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In re Japanese Application of

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for: "RADIO COMMUNICATIONS DEVICE AND SYSTEM"

VERIFICATION OF TRANSLATION

Honorable Commissioner of Patents and Trademarks

Washington, D.C. 20231

Sir:

Hideo IMABAYASHI residing at c/o WAKABAYASHI PATENT AGENCY, 16th Kowa Bldg., No.9-20, Akasaka 1-chome, Minato-ku, Tokyo 107-0052 Japan, declares:

(1) that he knows well both the Japanese and English languages;

(2) that he translated the above-identified Japanese Application from Japanese to English;

(3) that the attached English translation is a true and correct translation of the above-identified Japanese Application to the best of his knowledge and belief; and

(4) that all statements made of his own knowledge are true and that all statements made on information and belief and believed to be true, and further that these statements are made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 USC 1001, and that such false statements may jeopardize the validity of the application or any patent issuing thereof.

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/Hideo Imabayashi

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【Name of Document】 SCOPE OF CLAIMS

【Claim 1】

A radio communications device comprising:

a transmitting device comprising:

a transmission antenna section having a plurality of transmission antennas for radiating radio waves based on transmission RF signals;

a transmitter having a plurality of transmitting circuits for supplying the transmission RF signals to said transmission antenna section based on a plurality of transmission signals; and

a transmission signal processing section for outputting the transmission signals to said transmitter that are generated based on input transmission data, said transmission signal processing section including a modulator for generating said transmission signals having symbol rates;

a receiving device comprising:

a receiving antenna section having a plurality of reception antennas for receiving radio waves and outputting reception RF signals;

a receiver having a plurality of receiving circuits for outputting reception signals based on said reception RF signals input from said reception antenna section; and

a reception signal processing section for generating reception data based on the reception signals output from said receiver, said reception signal processing section including a demodulator for demodulating the reception signals having the symbol rates; and

propagation detecting section for detecting a propagating state of said radio waves; and

symbol rate setting section for selecting a symbol rate to be used for communication from the symbol rates based on the state detected by said propagating detecting section, and for setting the selected symbol rate in said modulator and said demodulator.

【Claim 2】

A radio communications device comprising:

a transmitting device comprising:

a transmission antenna section having a plurality of transmission antennas for radiating radio waves based on transmission RF signals;

a transmitter having a plurality of transmitting circuits for supplying the transmission RF signals to said transmission antenna section based on a plurality of transmission signals; and

a transmission signal processing section for outputting the transmission signals to said transmitter that are generated based on input transmission data, said transmission signal processing section including a modulator having a plurality of modulating circuits for generating said transmission signals having symbol rates;

a receiving device comprising:

a receiving antenna section having a plurality of reception antennas for receiving radio waves and outputting reception RF signals;

a receiver having a plurality of receiving circuits for outputting reception signals based on said reception RF signals input from said reception antenna section; and

a reception signal processing section for generating reception data based on the reception signals output from said receiver, said reception signal processing section including a demodulator having a plurality of demodulating circuits for demodulating the reception signals having the symbol rates; and

propagation detecting section for detecting a propagating state of said radio waves; and

symbol rate setting section for selecting a modulating circuit and a demodulating circuit having a symbol rate to be used for communication from the plurality of modulating circuits and the plurality of demodulating circuits based on the state detected by said propagating detecting section, and for setting the selected symbol modulating circuit and selected symbol demodulating circuit in said modulator and in said demodulator.

【Claim 3】

The radio communications device according to claim 1 or 2, wherein said propagation detecting section detects the propagating state of said radio waves according to at least one of the following: the level of a reception electric power, a transmission error rate, a retransmission rate, or a channel matrix estimated in a spatial multiplexing process.

【Claim 4】

The radio communications device according to claim 3, further comprising a control section for determining the intensity of multipath interference from the propagating state of said radio waves as detected by said propagation detecting section, said control section instructing said

symbol rate setting section to select a high symbol rate when it is determined that multipath interference is weak, and instructing said symbol rate setting section to select a low symbol rate when it is determined that multipath interference is strong.

【Claim 5】

The radio communications device according to claim 4, wherein said modulator and said demodulator lower the multilevel of modulation and demodulation when said high symbol rate is selected, and increase the multilevel of modulation and demodulation when said low symbol rate is selected.

【Claim 6】

The radio communications device according to claim 4 or 5, wherein said transmission signal processing section and said reception signal processing section reduce the number of said transmitting circuit to be used and the number of said receiving circuit to be used when said high symbol rate is selected, and increase the number of said transmitting circuit to be used and the number of said receiving circuit to be used when said low symbol rate is selected.

【Claim 7】

The radio communications device according to claim 4 or 5, wherein said control section instructs said transmission signal processing section and said reception signal processing section to use one of said plurality of transmitting circuits and one of said plurality of receiving circuits,

respectively, when it is determined that multipath interference is weak, and instructs said transmission signal processing section and said reception signal processing section to use said plurality of transmitting circuits and said plurality of receiving circuits, respectively, when it is determined that multipath interference is strong.

【Claim 8】

The radio communications device according to claim 4 or 5, wherein said modulator has modulation modes including a direct modulation mode for directly modulating said transmission data into a transmission carrier and an indirect modulation mode for modulating said transmission data into a transmission carrier after the transmission data are processed, said demodulator has demodulation modes including a direct demodulation mode for directly demodulating said reception signal to generate said reception data and an indirect demodulation mode for demodulating the reception signals and thereafter processing the demodulated reception signals to generate said reception data, said radio communications device further comprising a modulation/demodulation mode setting section for selecting and setting said modulation mode and said demodulation mode.

【Claim 9】

The radio communications device according to claim 8, wherein said control section instructs said modulator and said demodulator to use said direct modulation mode and said direct demodulation mode, respectively, when it is determined that multipath interference is weak, and instructs said modulator and said demodulator to use said indirect modulation mode and

said indirect demodulation mode, respectively, when it is determined that multipath interference is strong.

【Claim 10】

The radio communications device according to claim 8 or 9, wherein said control section instructs said modulator and said demodulator to select any one of modulating and demodulating processes including ASK, BPSK, FSK, QPSK, and DQPSK and to use one of said plurality of transmitting circuits and one of said plurality of receiving circuits, respectively, if it is determined that the multipath interference is weak, and instructs said modulator and said demodulator to select either of modulating and demodulating processes including multiphase PSK and multilevel QAM and to use said plurality of transmitting circuits and said plurality of receiving circuits, respectively, for spatial multiplex communications, when it is determined that the multipath interference is strong.

【Claim 11】

The radio communications device according to any one of claims 6, 7 and 10, further comprising a power supply control section for controlling power supplies of said plurality of transmitting circuits and said plurality of receiving circuits, respectively, said power supply control section stopping supplying electric power to the transmitting circuits and the receiving circuits which are not in use.

【Claim 12】

The radio communications device according to any one of claims 1 through 11, wherein said transmission antennas and said reception antennas are shared.

【Claim 13】

The radio communications device according to any one of claims 1 through 12, wherein said radio waves have a frequency of 10 GHz or higher.

【Claim 14】

A wireless communications system using a radio communications device according to any one of claims 1 through 13.

【Name of Document】 SPECIFICATION

【Title of the Invention】 RADIO COMMUNICATIONS DEVICE AND SYSTEM

【Technical Field】

【0001】

The present invention relates to a high-speed radio communications technique spatial multiplexing process.

【Background art】

【0002】

In recent years, efforts have been made to speed up radio communications systems such as microwave cellular phone systems, radio LAN systems, etc. by using multilevel modulation/demodulation and multiple carriers. However, there is a limitation imposed on the speeding-up efforts due to a narrow frequency band that can be used. For example, if multilevel PSK is employed, then the error rate is degraded and a very high performance level is required for phase noise and frequency stability of the oscillator. If multiple carriers are achieved by OFDM (Orthogonal Frequency Division Multiplexing), then the frequency band is determined by the product of the number of subcarriers and the symbol rate. Therefore, the frequency band needs to be wider as the system is speeded up. There is known another problem in that since the difference between the peak power and the average power is large, low-distortion transmission amplifiers are generally required.

【0003】

Consequently, there has been developed a radio communications system which incorporates the MIMO (Multi-Input Multi-Output) technology in

the microwave band. Fig. 15 is a block diagram of a radio communications device employing the above technology. Transmitter 1500 has transmitting circuits 1501-1 through 1501-3, antennas 1502-1 through 1502-3, and transmission signal processing circuit 1504. Transmission data is processed by transmission signal processing circuit 1504, and radiated as radio waves from antennas 1502-1 through 1502-3 by transmitting circuits 1501-1 through 501-3. Receiver 1506 has antennas 1508-1 through 1508-3, receiving circuits 1507-1 through 1507-3, and reception signal processing circuit 1510. The radio waves received by antennas 508-1 through 1508-3 are converted by receiving circuits 1507-1 through 1507-3 into reception signals, which are processed by reception signal processing circuit 1510 into reception data that is output. Reception signal processing circuit 1510 also outputs a channel matrix. The MIMO radio communication device is a radio communications device made up of a transmitter with antennas and a receiver with antennas, or a plurality of antennas and a plurality of transceivers, and performs communications according to a spatial multiplexing process.

【0004】

To the extent of the number of communications paths (independent spatial transmission paths), including multipaths, which can be orthogonalized, the transmission rate is proportional to the number of antennas (either the number of transmission antennas or the number of reception antennas which is smaller). Therefore, the transmission rate can be increased while using the same frequency and the same time. Using time-space coding, a spatial diversity effect is produced to obtain a good SNR (Signal to Noise Ratio).

【0005】

In general, as the frequency is higher, the radio wave tends to travel straighter, which differentiates a propagative environment. The frequency at which the propagative environment changes is said to be about 10 GHz. Beyond that frequency, it is difficult to perform non-line-of-sight communications. For example, according to "Propagation data and prediction methods for the planning of indoor radio communication systems and radio local area networks in the frequency range 900 MHz to 100 GHz", ITU-R, P. 1238-3, April 2003, power loss coefficients representing the attenuated amount of radio waves over the distance that the radio waves are propagated are in the range from 28 to 32 in the frequency range from 0.9 to 5.2 GHz in offices, and 22 at the frequency of 60 GHz. Since the power loss coefficient is 20 for a free space loss, scattering and diffraction are considered to be less influential at high frequencies such as 60 GHz. Multipaths are considered to be relatively few though the intensity of radio waves is occasionally strong in some multipaths. A radio system employing millimeter waves, e.g., in the 60 GHz band is described in a document by K. Ohata, et. al. (IEEE MTT-S International Microwave Symposium. Digest, June 2003. pp. 373 - 376). The modulation process that is used is ASK (digital amplitude modulation), and a high rate of 1.25 Gbits/sec. is achieved for radio communications.

【0006】

According to JP-H9-219672A、 as a technique to use a plurality of receivers, there is known a radio communications device comprising a plurality of antennas, a plurality of receivers, a plurality of demodulator, a S/N measuring unit, a correlator, a weighted-value output unit and a majority

decision unit. The receivers are connected with respective antennas. The demodulator demodulates the outputs of the receivers. The S/N measuring unit determines S/N from the output (R1, R2) of each receiver and calculates, from the S/N, the error rate (P1, P2) and the right answer rate (1-P1, 1-P2) of the output (D1, D2) of each demodulator. The correlator determines a correlative value (C1, C2) between the output (R1, R2) of each receiver when a signal having a specific pattern is output from the transmission side, and the signal having the specific pattern. The weighted-value output unit determines, from the error rate (P1, P2) and the right answer rate (1-P1, 1-P2) obtained by the S/N measuring unit and the correlative value (C1, C2) obtained by the correlator, the values of weight ($\omega 1$, $\omega 2$) for the output data (D1, D2) of each demodulator and the values of weight ($\omega 1^*$, $\omega 2^*$) for the data (D1*, D2*) having the polarity opposite to the polarity of the output data of the demodulator. The majority decision unit calculates the sum of the values of weight that correspond to data "0", and the sum of the values of weight that correspond to data "1", among the output data (D1, D2) of each demodulator and the data (D1*, D2*) having the polarity opposite to the polarity of the output data of the demodulator, and determines that data ("0" or "1") having larger sum is a correct data.

【0007】

In addition, according to JP2003-318999A, as a technique concerning OFDM, there is known a technique concerning a modulating circuit for performing a digital modulation, comprising a modulating means at an input stage, a spread means at an intermediate stage, an OFDM modulating means at an output stage and a path switching means. The modulating means changes any one of the group consisting of a phase, an amplitude

and a frequency of a carrier wave or any combination thereof based on digital information. One or more modulating means are disposed at an input stage for data signals to be modulated. The spread means provides spread modulation to the digital information using spread codes. One or more spread means are disposed at the intermediate stage. The OFDM modulating means divides the digital information into a plurality of low-speed data signals for modulation. One or more OFDM modulating means are disposed at the output stage for the modulated data signals. The path switching means selects and switches a modulating processing path when data signals to be modulated pass the input stage, the intermediate stage and the output stage in this order for undergoing modulating processing. The path switching means selects a path where a modulating processing is not performed, at the intermediate stage and/or at the output stage.

【0008】

Moreover, according to JP-H5-335975A, there is known a technique concerning a radio transmission device comprising: a plurality of modulators, a synthesizer for synthesizing the outputs of the modulators, a common electric power amplifier for electric-amplifying the signal output from the synthesizer with a linear amplifying area as an operation region. The common electric power amplifier includes a dividing circuit, electric power amplifier and a synthesizing circuit. The dividing circuit divides a signal output from the synthesizer into a plurality of signals. The electric power amplifier electric-amplifies a signal output from the synthesizer with a linear amplifying area as an operation region. The synthesizing circuit synthesizes signals output from the electric power amplifier and provides the synthesized signal to an output terminal. The radio communications transmission device

comprises a switch means for the on and off control of a power supply to the electric power amplifier, and a control circuit including a first control means for generating a signal for the on and off control of the output of the modulator and a second control means for controlling the switch means based on the control of the first control means.

【0009】

Furthermore, according to JP-H8-139632A, there is known a technique concerning a narrow-band communications device comprising a receiving section, a digital signal processing means, a transmitting section, an electric field intensity detecting means, an indication means, and an electric power control means. The receiving section receives received radio waves. The digital signal processing means performs demodulation of the output from the receiving section and output of a modulated signal of an audio input. The transmitting section transmits transmission radio waves based on the output of the modulated signal from the digital signal processing means. The electric field intensity detecting means detects the electric field intensity of the output from the receiving section. The indication means indicates that the narrow-band communications device is at a reception mode or at a transmission mode. The electric power control means controls the power supply to a predetermined portion of the narrow-band communications device or the operating state of the narrow-band communications device depending on the output of the electric field intensity detecting means and/or the output of the indication means.

【0010】

According to Japanese patent No. 2736067, a radio telephone apparatus having a modulation means for modulating signals to be

modulated, comprises a power switch, a power supply means, a determination means, a power supply inhibiting means, a lock detection means and a control means. The power supply means supplies power to at least the modulation means. The determination means determines whether or not the modulation means should be at an operating condition. The power supply inhibiting means inhibits the supply of power to the modulation means if the determination means has not determined that the modulation means should be operative, when the power switch is on. The power supply means supplies power to the modulation means if the determination means has determined that the modulation means should be operative, when the power switch is on. Lock detection means detects that a phase synchronization loop that constitutes the modulation means, has locked up. The control means performs a control to supply a signal to be modulated to the modulation means in response to the detection of the lock up by the lock detection means.

【0011】

Further, according to JP-H9-93158A, there is known a technique concerning a receiving device in a spread spectral communications system employing a direct spread modulation scheme, the system comprising a plurality of reception antennas, a plurality of receiving circuits, a signal strength measuring means and a path switching circuit. The antennas are disposed with a predetermined interval. The receiving circuits each correspond to each of the plurality of antennas. The signal strength measuring means samples the output signals from the receiving circuits at a rate which is an integral multiple of one chip of a spread code sequence, and measures the strength of the sampled signal. The path switching circuit

selects one output signal from among the output signals from the receiving circuits based on the measuring result of the signal strength measuring means, and supplies the selected output signal to the demodulating circuit.

【0012】

Furthermore, according to JP-H7-154376A, there is known a technique concerning an after-detection selective synthesis diversity receiving device comprising a plurality of receivers that receive signals according to a time division multiplex access scheme. The diversity receiving device comprises level comparators, a delay device, a selector and a power control section. The level comparator compares the reception signals of part of slots to be received from the output signals of each detector in the receivers. The delay device has a delay time which is equal to the comparing processing time of the level comparator provided at the output side of each detector or at the output side of a demodulator which demodulates the output of each detector. The selector selects the output signals of the receivers based on the results of comparison by the level comparators. The power control section performs a control to stop the supply of power to at least part of receivers and level comparators which require no reception signals, based on the results of comparison by the level comparators.

【0013】

According to another configuration, the diversity receiving device is an after-detection selective synthesis diversity receiving device comprising a plurality of receivers that receive signals according to a time division multiplex access scheme, which comprises level detectors, delay devices, selectors, a demodulator and a power control section. The level comparator

compares the reception signals of part of slots to be received from the output signals of each detector in the receivers. The delay device has a delay time which is equal to the comparing processing time of the level comparator provided at the output side of each detector. The selector selects the output signals of the delay devices provided at the output side of each detector based on the results of comparison by the level comparators. The demodulator demodulates the detection signal selected by the selector. The power control section performs a control to stop the supply of power to at least part of receivers and level comparators which require no reception signals, based on the results of comparison by the level comparators. .

【0014】

In connection with the foregoing, JP-H7-162350A discloses a technique concerning an after-detection selective synthesis diversity receiving device comprising plural systems of receivers. The diversity receiving device comprises a power control section, level comparators and selectors. The diversity receiving device selects a reception signal through the selector at a predetermined interval based on the result of determination of the comparator, and controls through the power control section the supply of power to receivers and level comparators which requires no reception signals. The power control section controls the supply of power to each receiver. The level comparator compares a plurality of reception levels after detection. The selector selects a plurality of reception signals.

【0015】

【Patent Document 1】 JP-H9-219672

【Patent Document 2】 JP-2003-318999

【Patent Document 3】 JP-H5-335975

【Patent Document 4】 JP-H8-139632

【Patent Document 5】 Japanese Patent No. 2736067

【Patent Document 6】 JP-H9-93158

【Patent Document 7】 JP-H7-154376

【Patent Document 8】 JP-H7-162350

【Disclosure of the Invention】

【Problems to be solved by the invention】

【0016】

It is an object of the present invention to provide a radio communications device and a radio communications system which are capable of transmitting data at a high-rate while suppressing electric power consumption.

【0017】

It is anther object of the present invention to provide a radio communications device and a radio communications system which are hardly experience communication interruptions due to multipath interference.

【0018】

It is still another object of the present invention to provide a radio communications device and a radio communications system which are small in size.

【Means to solve the Problems】

【0019】

Means to solve the problems will be explained below using reference numerals and symbols which are used in “Best mode for carrying out the invention”. These reference numerals and symbols are intended to clarify the relationship between “Scope of Claims” and “Best mode for carrying out

the invention" and should not be used to interpret the technical scope of the inventions described in "Scope of Claims".

【0020】

According to one aspect of the invention, a radio communications device comprises a transmitting device (100, 200, 300, 400), a receiving device (106, 206, 306, 406), a propagation detecting section (110, 111, 112, 210, 211, 212, 310, 311, 312, 410, 411, 412) and a symbol rate setting section. The transmitting device (100, 200, 300, 400) comprises a transmission antenna section (102-1～3,202-1 ～4 ,302-1 ～4,402-1～4), a transmitter and a transmission signal processing section (104, 204, 304, 404). The transmission antenna section has a plurality of transmission antennas for radiating radio waves based on transmission RF signals. The transmitter has a plurality of transmitting circuits (101-1～3,201-1 ～4,301-1 ～4,401-1～4) for supplying the transmission RF signals to said transmission antenna section based on a plurality of transmission signals. The transmission signal processing section outputs the transmission signals to said transmitter that are generated based on input transmission data. Said transmission signal processing section includes a modulator (105, 205, 305, 405) for generating said transmission signals having symbol rates. The receiving device (106, 206, 306, 406) comprises a receiving antenna section (108-1～3,208-1～4, 308-1～4,408 -1～4), a receiver and a reception signal processing section (110, 210, 310, 410). The receiving antenna section has a plurality of reception antennas (108-1～3,208-1～4, 308-1～4,408 -1～3) for receiving radio waves and outputting reception RF signals. The receiver has a plurality of receiving circuits (107-1～3,207-1～4,307-1～3,407-1～3) for outputting reception signals based on said reception RF signals input

from said reception antenna section. The reception signal processing section generates reception data based on the reception signals output from said receiver. Said reception signal processing section also includes a demodulator for demodulating the reception signals having the symbol rates. The propagation detecting section detects a propagating state of said radio waves. The symbol rate setting section selects a symbol rate to be used for communication from the symbol rates based on the state detected by said propagating detecting section, and sets the selected symbol rate in said modulator and said demodulator.

【0021】

According to another aspect of the invention, a radio communications device comprises a transmitting device (100, 200, 300, 400), a receiving device (106, 206, 306, 406), a propagation detecting section (110, 111, 112, 210, 211, 212, 310, 311, 312, 410, 411, 412) and a symbol rate setting section. The transmitting device (100, 200, 300, 400) comprises a transmission antenna section (102-1～3,202-1～4,302-1～3,402-1～3), a transmitter and a transmission signal processing section (104, 204, 304, 404). The transmission antenna section has a plurality of transmission antennas for radiating radio waves based on transmission RF signals. The transmitter has a plurality of transmitting circuits (101-1～3, 201-1～4, 301-1～4, 401-1～3) for supplying the transmission RF signals to said transmission antenna section based on a plurality of transmission signals. The transmission signal processing section outputs the transmission signals to said transmitter that are generated based on input transmission data. Said transmission signal processing section includes a modulator (105, 205, 305, 405) for generating said transmission signals having symbol rates. The

receiving device (106, 206, 306, 406) comprises a receiving antenna section (108-1～3, 208-1～4, 308-1～3, 408-1～3), a receiver and a reception signal processing section (110, 210, 310, 410). The receiving antenna section has a plurality of reception antennas (108-1～3, 208-1～4, 308-1～3, 408-1～3) for receiving radio waves and outputting reception RF signals. The receiver has a plurality of receiving circuits (107-1～3, 207-1～4, 307-1～3, 407-1～3) for outputting reception signals based on said reception RF signals input from said reception antenna section. The reception signal processing section generates reception data based on the reception signals output from said receiver. Said reception signal processing section also includes a demodulator for demodulating the reception signals having the symbol rates. The propagation detecting section detects a propagating state of said radio waves. Symbol rate setting section selects a modulating circuit and a demodulating circuit having a symbol rate to be used for communication from the plurality of modulating circuits and the plurality of demodulating circuits based on the state detected by said propagating detecting section, and sets the selected modulating circuit and the selected demodulating circuit in said modulator and said demodulator.

【0022】

Said propagation detecting section (110, 111, 112, 210, 211, 212, 310, 311, 312, 410, 411, 412) of the radio communications device according to the present invention detects the propagating state of said radio waves according to at least one of the following: the level of a reception electric power, a transmission error rate, a retransmission rate, or a channel matrix estimated in a spatial multiplexing process.

【0023】

The radio communications device according to the present invention further comprises a control section. The control section determines the intensity of multipath interference from the propagating state of said radio waves as detected by said propagation detecting section. Said control section instructs said symbol rate setting section to select a high symbol rate when it is determined that multipath interference is weak. Said control section instructs said symbol rate setting section to select a low symbol rate when it is determined that multipath interference is strong.

【0024】

Said modulator (105, 205, 305, 405) and said demodulator (106, 206, 306, 406) of the radio communications device according to the present invention lower the multilevel of modulation and demodulation when said high symbol rate is selected, and increase the multilevel of modulation and demodulation when said low symbol rate is selected.

【0025】

Said transmission signal processing section (105, 205, 305, 405) and said reception signal processing section (106, 206, 306, 406) of the radio communications device according to the present invention reduce the number of said transmitting circuit to be used and the number of said receiving circuit to be used when said high symbol rate is selected, and increase the number of said transmitting circuit to be used and the number of said receiving circuit to be used when said low symbol rate is selected.

【0026】

Said control section of the radio communications device according to the present invention instructs said transmission signal processing section (105, 205, 305, 405) and said reception signal processing section (106, 206,

306, 406) to use one of said plurality of transmitting circuits and one of said plurality of receiving circuits, respectively, when it is determined that multipath interference is weak, and instructs said transmission signal processing section and said reception signal processing section to use said plurality of transmitting circuits and said plurality of receiving circuits, respectively, when it is determined that multipath interference is strong.

【0027】

Said modulator of the radio communications device according to the present invention has modulation modes. One modulation mode is a direct modulation mode for directly modulating said transmission data into a transmission carrier. The other modulation mode is an indirect modulation mode for modulating said transmission data into a transmission carrier after the transmission data are processed. Said demodulator has demodulation modes. One demodulation mode is a direct demodulation mode for directly demodulating said reception signal to generate said reception data. The other demodulation mode is an indirect demodulation mode for demodulating the reception signals and thereafter processing the demodulated reception signals to generate said reception data. The radio communications device according to the present invention further comprises modulation/demodulation mode setting section (415, 416) for selecting and setting said modulation mode and said demodulation mode.

【0028】

Said control section of the radio communications device according to the present invention instructs said modulator and said demodulator to use said direct modulation mode and said direct demodulation mode, respectively, when it is determined that multipath interference is weak, and

instructs said modulator and said demodulator to use said indirect modulation mode and said indirect demodulation mode, respectively, when it is determined that multipath interference is strong.

【0029】

Said control section of the radio communications device according to the present invention instructs said modulator and said demodulator to select any one of modulating and demodulating processes including ASK, BPSK, FSK, QPSK, and DQPSK and to use one of said plurality of transmitting circuits and one of said plurality of receiving circuits, respectively, if it is determined that the multipath interference is weak, and instructs said modulator and said demodulator to select either of modulating and demodulating processes including multiphase PSK and multilevel QAM and to use said plurality of transmitting circuits and said plurality of receiving circuits, respectively, when it is determined that the multipath interference is strong. At this time, a spatial multiplex communication is performed using the transmission circuits and the reception circuits.

【0030】

The radio communications device according to the present invention comprises a power supply control section for controlling power supplies of said plurality of transmitting circuits (101-1～3,201-1～4,301-1～4,401-1～3) and said plurality of receiving circuits (107-1～3,207-1～4,307-1～3,407-1～3), respectively. Said power supply control section (103, 109, 203, 209, 303, 309, 403, 409) stops supplying electric power to the transmitting circuits and the receiving circuits which are not in use.

【0031】

Said transmission antennas (102-1～3, 202-1～4, 302-1～3, 402-1～3) and said reception antennas (108-1～3, 208-1～4, 308-1～3 ,408-1～3) of the radio communications device according to the present invention are shared.

【0032】

Said radio waves of the radio communications device according to the present invention have a frequency of 10 GHz or higher.

【0033】

A radio communications system according to the present invention uses any of the above-described radio communications devices.

【Effects of the Invention】

【0034】

According to the present invention, it is possible to provide a radio communications device and a radio communications system which are capable of transmitting data at a high-rate while suppressing electric power consumption.

【0035】

Further, according to the present invention, it is possible to provide a radio communications device and a radio communications system which are hardly experience communication interruptions due to multipath interference.

【0036】

Furthermore, according to the present invention, it is possible to provide a radio communications device and a radio communications system which are small in size.

【Best mode for carrying out the invention】

【0037】

Radio communications devices incorporating MIMO technology consume a large amount of electric power because a plurality of transmitters and receivers are operated. MIMO processing circuit estimates a channel matrix and converts and distributes transmission signals to a plurality of transmitters, and the reception signal processing circuit has a function to combine and convert reception signals from a plurality of receivers, resulting in consumption of a large amount of electric power. Electric Power consumption is also increased by high-rate D/A converters (DACs), A/D converters (ADCs), and time-space coding circuits.

【0038】

According to a literature by Karasawa, et. al. (2003, IEICE Society Conference, Lecture Transactions 1, SS-30, Lecture No. TB-2-1), if the antenna interval is a one-half wavelength or longer, then when multipaths arrive in a wide angular range, the elements of the channel response matrix vary noncorrelatively. At this time, the transmission capacity increases, but the one-half wavelength becomes about 6 cm at 2.4 GHz, for example. If there is no local scattering in line-of-sight communications, then it is desirable that the antenna interval be increased by a considerable distance. A literature by D. Gesbert (IEEE Journal on Selected Areas in Communications, Vol. 21, No. 3, April 2003) shows 10 wavelengths as the element-to-element interval of four-element antennas for use on base stations in a cellular phone system in the above environment. The disclosed antenna interval as applied to portable terminals and microwave radio communications device for use in offices and homes is not practical in terms of size.

【0039】

Radio systems employing millimeter waves, e.g., in the 60 GHz band, use ASK (Amplitude Shift Keying), FSK (Frequency Shift Keying), or BPSK (Binary Phase Shift Keying) of a low modulation index, and mostly utilize point-to-point communications with a narrowed antenna beam. If the antenna beam is widened, then the signal quality is lowered or a transmission failure occurs due to multipath interference especially in indoor communications. This is because if the symbol rate is increased, the delay time (the difference between arrival times of direct and reflected waves) is broadened relatively largely as compared with the symbol length, giving rise to an intersymbol interference. In order to lower the symbol rate to avoid an intersymbol interference and maintain high-rate communications, there is employed a radio communication device using multivalued QAM (Quadrature Amplitude Modulation) or QAM as primary modulation and OFDM as secondary modulation. However, such a radio communications device suffers practical problems because the oscillator is required to have low phase noise characteristics and frequency stability, the transmission amplifier is required to be highly linear, and, in particular, radio communications devices for use in the millimeter wave range are complex, highly costly, and large in size.

【0040】

Fig. 1 is a block diagram of a radio communications device according to a first embodiment of the present invention. The radio communications device comprises transmitting device 100 and receiving device 106. Since communications are normally bidirectional, a plurality of radio communications devices are positioned in facing relation to each other for communications therebetween. In this embodiment, transmitting device 100

and receiving device 106 may be a transmitting section and a receiving section, respectively, of radio communications devices that face each other. Further, although not shown, the radio communications device has a control section for controlling the operation of the radio communication device by estimating multipath interference, and judging whether or not the error rate is good.

【0041】

Transmitting device 100 comprises a plurality of transmitters, power supply control circuit 103 and MIMO processing circuit 104. The plurality of transmitters include a transmitter having transmitting circuit 101-1 connected with antenna 102-1, a transmitter having transmitting circuit 101-2 connected with antenna 102-2 and a transmitter having transmitting circuit 101-3 connected with antenna 102-3.

【0042】

Power supply control circuit 103 controls the supply of power to be supplied to transmitting circuits 101-1 through 101-3 based on a power supply control signal. MIMO processing circuit 104 has at least one of or all of a modulating function, a coding function and a weighting/mapping function. MIMO processing circuit 104 includes modulator 105 and is capable of changing a symbol rate and the number of multilevel of modulation according to a modulation control signal. MIMO processing circuit 104 outputs the transmission signal generated based on the input signal and the modulation control signal to transmitting circuits 101-1 through 101-3.

【0043】

Receiving device 106 comprises a plurality of receivers, power supply control circuit 109, MIMO processing circuit 111, level detector 111 and error rate measuring unit 112. The plurality of receivers comprises a receiver having receiving circuit 107-1 connected to antenna 108-1, a receiver having receiving circuit 107-2 connected to antenna 108-2, and a receiver having receiving circuit 107-3 connected to antenna 108-3.

【0044】

Power supply control circuit 109 controls power to be supplied to receiving circuits 107-1 through 107-3 based on a power supply control signal. MIMO processing circuit 110 has at least one of or all of a modulating function, a decoding function and a weighting/mapping function. MIMO processing circuit 110 generates reception data based on the reception signals input from receiving circuits 107-1 through 107-3 and outputs the reception data. MIMO processing circuit 110 estimates a channel matrix based on the reception signals input from receiving circuits 107-1 through 107-3, and outputs the estimated channel matrix. Level detector 111 detects a reception level based on reception level signals input from receiving circuits 107-1 through 107-3, and outputs the detected reception level. Error rate measuring unit 112 measures a bit error rate or a frame error rate based on the reception data output from MIMO processing circuit 110, and outputs the error rate.

【0045】

In the radio communications device, a symbol rate is determined as shown in Fig. 5. A control section estimates the intensity of multipath interference based on the reception level output from level detector 111, the

error rate output from error rate measuring unit 112, and the channel matrix output from MIMO processing circuit 110 (step S11).

【0046】

If it is determined that the multipath interference is strong (step S13-YES), then the control section outputs a modulation control signal to set a symbol rate to a low value. MIMO processing circuit 104 lowers the symbol rate in modulator 105 or selects a modulating circuit having a low symbol rate to change the symbol rate to be modulated. MIMO processing circuit 110 lowers the symbol rate in the demodulator or selects a demodulator having a low symbol rate to change the symbol rate to be demodulated (step S17).

【0047】

If it is determined that the multipath interference is weak (step S13-NO) , then the control section outputs a modulation control signal to set a symbol rate to a high value . MIMO processing circuit 104 increases the symbol rate in modulator 105 or selects a modulating circuit having a high symbol rate to change the symbol rate to be modulated. MIMO processing circuit 110 increases the symbol rate in the demodulator or selects a demodulator having a high symbol rate to change the symbol rate to be demodulated (step S15). After the symbol rate is determined, communications are performed for normal data transmission.

【0048】

In the present embodiment, it is essential to determine the extent of multipath interference based on a signal propagating state. Although not shown herein, the station's own signal propagating state or the signal propagating state of another station can be known during a preamble period

to synchronize the station with the other station or during a period in which communications are made for data transmission. During the communications, the signal propagating state of the other station can be received as part of the data that are transmitted. The stations' own signal propagating state is sent to the other station.

【0049】

The signal propagating state is calculated from the reception level output from level detector 111, the error rate output from error rate measuring unit 112, and the channel matrix output from MIMO processing circuit 110. The signal propagating state can be represented by the number of independent spatial transmission paths which can contribute to communications, the rate of retransmission requests due to errors, etc. For example, as shown in Fig. 13, the intensity of multipath interference may be prescribed from the relationship between the received electric power and the error rate, and a multipath interference may be prescribed as being high if the error rate (or the rate of retransmission requests due to errors) is high though the received electric power is high. Furthermore, as shown in Fig. 14, the number of independent spatial transmission paths which can contribute to communications may be determined from an inherent value that is calculated from the estimated channel matrix, and the extent of a multipath interference may be determined therefrom. These processes may be combined with each other, or the extent of a multipath interference may be prescribed stepwise. Naturally, it is also possible to initially set the symbol rate to a low value and then increase the symbol rate stepwise.

【0050】

According to the present embodiment, when the extent of multipath interference is small, high-rate transmission is made possible by setting the symbol rate to a high value. In this case, the correlated bandwidth often widens, making the apparatus advantageous for a high symbol rate, i.e., wide-band transmission.

【0051】

Radio communications devices using frequencies of 10 GHz or higher, particularly frequencies of millimeter waves (30 to 300 GHz), even with an array of antennas, have an antenna size smaller than radio communications devices using the microwave band. For example, if a radio communications device uses a frequency of 60 GHz, then the antenna interval is about 2.5 mm for a one-half wavelength and about 2.5 cm for 10 wavelengths. In terms of size, the radio communications device can be used as a portable terminal or as radio communications device in offices and homes.

【0052】

A first variant of the first embodiment will be described below with reference to Fig. 6. The first variant is concerned with another process of determining a symbol rate. The radio communications device according to the first variant is structurally identical to the radio communication device according the first embodiment, and is capable of changing the symbol rate based on the modulation control signal.

【0053】

First, a symbol rate is set to a high value. Specifically, a high symbol rate is set in the modulator and in the demodulator, or alternatively a modulator and a demodulator having a high symbol rate are used (step S21).

Error rate measuring unit 112 measures an error rate (step S21). The control section determines whether or not the error rate is in a range which is sufficiently allowable for communications. If the error rate is not sufficiently allowable (step S25-NO), then the symbol rate is lowered by one level based on the modulation control signal. Specifically, a symbol rate is lowered by one level in the modulator and the demodulator, or alternatively a modulator and a demodulator having a one level lower symbol rate are used (step S27). . Thereafter, control goes back to step S23 to measure an error rate again under new conditions. The symbol rate is lowered until the error rate falls within the sufficiently allowable range (step S25-YES). Therefore, the symbol rate is lowered until the error rate becomes sufficiently low.

【0054】

The above process can be carried out prior to the start of communication. However, even during data communications, the bit error rate, the frame error rate, the packet error rate, and the retransmission request rate (retransmission rate) may be monitored, and the symbol rate may be lowered to make the numerical values of these rates sufficiently lower. Furthermore, the first variant may include a process wherein if the error rates are sufficiently lowered, then it is determined that multipath interference is reduced and the symbol rate is increased to increase the transmission rate again. The present variant offers the same advantages as the first embodiment, but allows conditions to be set more highly depending on the situation for high-rate transmission.

【0055】

A second variant of the first embodiment will be described below with reference to Fig..7. The second variant is concerned with a process of

determining a symbol rate and the number of multiple values of modulation. The radio communications device according to the second variant is structurally identical to the radio communication device according the first embodiment, and is capable of changing the number of multiple values of modulation and the symbol rate based on the modulation control signal and the propagating situation communication signal.

【0056】

First, the intensity of multipath interference is estimated (step S31). If it is determined that multipath interference is weak (step S33-NO), then the symbol rate is set to a high value and the number of multilevel of modulation is set to a small value. Specifically, the modulator and the demodulator are set to those values or such a modulator and a demodulator are used. If it is determined that the multipath interference is strong (step S33-YES), then the symbol rate is set to a low value and the number of multilevel of modulation is set to a large value. Specifically, the modulator and the demodulator are set to those values or such a modulator and a demodulator are used. Using the symbol rate and the number of multiple values of modulation thus set, subsequent communications are performed.

【0057】

Multipath interference may be determined in the same manner as described in the first embodiment. According to the present variant, if the extent of a multipath interference is small, then the symbol rate may be increased to perform high-rate transmission. Even if multipath interference is strong and the correlated bandwidth is small, the symbol rate may be lowered and the signal band may be narrowed to enable efficient transmission.

【0058】

A third variant of the first embodiment will be described below with reference to Fig. 8. The third variant is concerned with another process of determining a symbol rate and the number of multiple values of modulation. The radio communications device according to the third variant is structurally identical to the radio communication device according the first embodiment, and is capable of changing the number of multiple values of modulation and the symbol rate based on the modulation control signal and the propagating situation communication signal.

【0059】

First, the symbol rate is set to a high value and the number of multilevel of modulation is set to a low value as initial states (step S41). Error rate measuring unit 112 measures an error rate (step S43). It is determined whether or not the error rate is in a range which is sufficiently allowable in communications. If the error rate is not sufficiently allowable (step S45-NO), then the number of multilevel of modulation is increased and the symbol rate is set to a lower value (step S47). Control goes back to step S43 to measure an error rate again under new conditions. The symbol rate is lowered and the number of multilevel of modulation is increased until the error rate falls within the sufficiently allowable range (step S45-YES). Therefore, the symbol rate is lowered until the error rate becomes sufficiently low and the number of multilevel is increased.

【0060】

The above process can be carried out prior to the start of communications. However, even during data communications, the bit error rate, the frame error rate, the packet error rate, and the retransmission

request rate may be monitored, and the symbol rate may be appropriately lowered and the number of multiple values may be appropriately increased to make the numerical values of these rates sufficiently lower. Furthermore, the third variant may include a process wherein if the error rates are sufficiently lowered, then it is determined that the multipath interference is reduced and the symbol rate is increased to increase the transmission rate again. The present variant offers the same advantages as the first variant, but allows conditions to be set more highly depending on the situation for high-rate transmission.

【0061】

A fourth variant of the first embodiment will be described below with reference to Fig. 9. The fourth variant is concerned with an operation process including a process of determining a symbol rate. According to the fourth variant, the radio communication device is structurally identical to the radio communication device according to the first embodiment, and is capable of changing the symbol rate based on the modulation control signal and the propagating situation communication signal.

【0062】

First, the intensity of multipath interference is estimated according to the process described in the first embodiment (step S51), for example. If it is determined that multipath interference is strong (step S53-YES), then the symbol rate is set to a low value (step S55). If it is determined that multipath interference is weak (step S53-NO), then the symbol rate is set to a high value (step S57). In this case, the power supplies of those transmitting and receiving circuits which do not contribute to the transmission rate are turned off in order to reduce electric power consumption (step S58). Stated

otherwise, the power supplies of those circuits which do not operate are turned off to reduce electric power consumption.

【0063】

In a line-of-sight environment with reduced multipath interference, the correlation between antenna elements increases. Therefore, even if MIMO technology is employed, the transmission capacity is not increased and a spatial diversity effect is not produced. This tendency is particularly strong in radio communications at frequencies of 10 GHz or higher, particularly millimeter waves (30 to 300 GHz) frequencies, because no local scattering is expected. Consequently, even if priority is given to the reduction of electric power consumption, communication quality (transmission rate, SNR, etc.) is not greatly degraded. The present variant offers the same advantages as the first embodiment, but is effective to avoid unnecessary consumption of electric power in the absence of multipath interference.

【0064】

A fifth variant of the first embodiment will be described below with reference to Fig. 10. The fifth variant is concerned with another operation process including a process of determining a symbol rate and the number of multiple values of modulation. The radio communications device according to the fifth variant, is structurally identical to the radio communications device according the first embodiment, and is capable of changing the number of multiple values of modulation and the symbol rate based on the modulation control signal and the propagating situation communication signal.

【0065】

First, the intensity of multipath interference is estimated according to the process described in the first embodiment (step S61), for example. If it is

determined that multipath interference is strong (step S63-YES)., then the symbol rate is set to a low value and a modulation scheme where the number of multilevel of modulation is high is selected (step S65). If it is determined that multipath interference is weak (step S63-NO), then the symbol rate is set to a high value and a modulation scheme where the number of multilevel of modulation is low is selected (step S675). In this case, the power supplies of those transmitting and receiving circuits which do not contribute to the transmission rate are turned off in order to reduce electric power consumption (step S68). Stated otherwise, the power supplies of those circuits which do not operate are turned off to reduce electric power consumption.

【0066】

The present variant differs from the fourth variant in that if it is determined that interference is weak, then the symbol rate is set to a high value and the number of multiple values of modulation is set to a low value, and if it is determined that the interference is strong, then the symbol rate is set to a low value and the number of multiple values of modulation is set to a high value. The present variant offers the same advantages as the fourth variant, but allows conditions to be set more highly depending on the situation for high-rate transmission.

【0067】

Fig. 2 is a block diagram of a radio communications device according to a second embodiment of the present invention. According to the second embodiment, the radio communications device has a direct modulation/demodulation mode and an indirect modulation/demodulation mode. The direct modulation mode refers to a process of modulating

transmission data directly into a transmission carrier. The indirect modulation mode refers to a process of processing transmission data, thereafter modulating the processed transmission data into a transmission carrier and up-converting the transmission carrier into a carrier in a radio frequency band. The direct demodulation mode refers to a process of modulating a reception signal directly into reception data. The indirect demodulation mode refers to a process of down-converting the carrier from the radio frequency band, demodulating a reception signal, and thereafter processing the signal into reception data.

【0068】

The radio communications device has transmitting device 200 and receiving device 206. Since communications are normally bidirectional, a plurality of radio communications devices are positioned in facing relation to each other for communications therebetween. In this embodiment, transmitting device 200 and receiving device 206 are a transmitter and a receiver, respectively. Further, although not shown, the radio communications device has a control section for controlling the operation of the radio communication device by estimating multipath interference, and judging whether or not the error rate is good..

【0069】

Transmitting device 200 comprises a plurality of transmitters, power supply control circuit 203 and MIMO processing circuit 204. The plurality of transmitters include a transmitter having transmitting circuit 201-1 in the indirect modulation mode connected with antenna 202-1, a transmitter having transmitting circuit 201-2 in the indirect modulation mode connected with antenna 202-2 and a transmitter having transmitting circuit 201-3 in the

indirect modulation mode connected with antenna 202-3 and a transmitter having transmitting circuit 201-4 in the indirect modulation mode connected with antenna 202-4. Transmitting circuit 201-1~3 are supplied with transmission signals via MIMO processing circuit 204, and transmitting circuit 201-4 is directly supplied with a transmission signal not via MIMO processing circuit 204.

【0070】

Power supply control circuit 203 controls the supply of power to be supplied to transmitting circuits 201-1 through 201-3 based on a power supply control signal. MIMO processing circuit 204 has at least one of or all of a modulating function, a coding function and a weighting/mapping function. MIMO processing circuit 204 includes modulator 205 and is capable of changing a symbol rate and the number of multilevel of modulation according to a modulation control signal. MIMO processing circuit 204 outputs the transmission signal generated based on the input signal and the modulation control signal to transmitting circuits 201-1 through 201-3.

【0071】

Receiving device 206 comprises a plurality of receivers, power supply control circuit 209, MIMO processing circuit 210, level detector 211 and error rate measuring unit 212. The plurality of receivers comprises a receiver having receiving circuit 207-1 in the indirect demodulation mode connected to antenna 208-1, a receiver having receiving circuit 207-2 in the indirect demodulation mode connected to antenna 208-2, and a receiver having receiving circuit 207-3 in the indirect demodulation mode connected to antenna 208-3 and a receiver having receiving circuit 207-4 in the direct

demodulation mode connected to antenna 208-4. Power supply control circuit 209 controls power to be supplied to receiving circuits 207-1 through 207-3 based on a power supply control signal. MIMO processing circuit 210 has at least one of or all of a modulating function, a decoding function and a weighting/mapping function. MIMO processing circuit 210 generates reception data based on the reception signals input from receiving circuits 207-1 through 207-3 and outputs the reception data. MIMO processing circuit 210 estimates a channel matrix based on the reception signals input from receiving circuits 207-1 through 207-3, and outputs the estimated channel matrix. Level detector 211 detects a reception level based on reception level signals input from receiving circuits 207-1 through 207-3, and outputs the detected reception level. Error rate measuring unit 212 measures a bit error rate or a frame error rate based on the reception data output from MIMO processing circuit 210 and receiving circuit 207-4 , and outputs the error rate.

【0072】

Transmitting circuit 204-4 and receiving circuit 207-4 employ any one of ASK, FSK, BPSK, QPSK and DQPSSK as a modulation/demodulation process. Transmitting circuit 204-4 modulates input data into a transmission carrier, and receiving circuit 207-4 demodulates data directly from a reception signal. Such modulation/demodulation is referred to as direct modulation/demodulation. A symbol rate used in transmitting circuit 204-4 and receiving circuit 207-4 is set to a value higher than the symbol rate used in transmitting circuits 201-1 through 201-3 and in receiving circuits 207-1 through 207-3 in the indirect modulation/demodulation mode. The indirect modulation/demodulation mode may employ either multilevel PSK or

multilevel QAM, or OFDM using multilevel PSK or multilevel QAM for primary modulation.

【0073】

The transmitting and receiving circuits of the radio communications device are set to operate as shown in Fig. 11. First, the power supply of transmitting circuit 201-4 is turned on by power supply control circuit 203, and the power supply of receiving circuit 207-4 is turned on by power supply control circuit 209 (step S71). The power supplies of transmitting circuits 201-1 through 201-3 are turned off by power supply control circuit 203, and the power supplies of receiving circuits 207-1 through 207-3 are turned off by power supply control circuit 209 (step S72). Then, error rate measuring unit 212 measures an error rate (step S73). The control section determines whether or not the error rate is in a range which is sufficiently allowable or not for communications. If the error rate is sufficiently allowable (step S74-YES), then subsequent communications are performed with the above configuration. Specifically, communications are performed using transmitting circuit 201-4 and receiving circuit 207-4. If it is determined that the error rate is not sufficiently allowable (step S74-NO) , then the power supply of transmitting circuit 201-4 is turned off by power supply control circuit 203, and the power supply of receiving circuit 207-4 is turned off by power supply control circuit 209 . Therefore, transmitting circuit 201-4 and receiving circuit 207-4 are not operated. The power supplies of transmitting circuits 201-1 through 201-3 are turned on by power supply control circuit 203, and the power supplies of receiving circuits 207-1 through 207-3 are turned on by power supply control circuit 209, to make these circuits operable (step S77). Finally, a setting process is performed in which radio communications

according to the normal MIMO process are set, or a symbol rate and the number of multilevel of modulation are determined according to any one of the processes described above in the first embodiment and the variants thereof (step S78).

【0074】

According to the present embodiment, if multipath interference is weak, then the power supplies of circuits which consume a large amount of electric power, such as high-rate D/A converters (DACs), A/D converters (ADCs), MIMO processing circuits, and time-space coding circuits are turned off, for thereby achieving low electric power consumption. If ASK is used for direct modulation/demodulation, then as described in the literature by K. Ohata referred to above, the transmission rate of 1.25 Gbits/sec. is achieved for radio communications, using the 60 GHz band. At this time, high-rate switches and detectors are required as devices that are necessary for modulation/demodulation. However, these devices generally consume a smaller amount of electric power than the above circuits. Therefore, if multipath interference is weak, then high-rate wide-band millimeter-wave communications can be achieved with low electric power consumption in the direct modulation/demodulation mode. If multipath interference is strong, then though the electric power consumption increases, the possibility of communication interruptions due to multipath interference is lowered, and hence communications can be continued while maintaining a certain degree of transmission rate.

【0075】

A variant of the second embodiment will be described below with reference to Fig.3. Fig. 3 is a block diagram of a radio communication

device according to the present variant. The radio communications device according to the present variant is essentially structurally the same as the radio communication device according to the second embodiment shown in Fig. 2, with components being denoted by different reference characters. The radio communications device has transmitter 300 and receiver 306. Further, although not shown, the radio communication device has a control section for controlling the operation of the radio communication device by estimating multipath interference, and judging whether or not the error rate is good.

【0076】

Transmitting device 300 comprises a plurality of transmitters, power supply control circuit 303 and MIMO processing circuit 304. The plurality of transmitters include a transmitter having transmitting circuit 301-1 in the indirect modulation mode connected with antenna 302-1, a transmitter having transmitting circuit 301-2 in the indirect modulation mode connected with antenna 302-2 and a transmitter having transmitting circuit 301-3 in the indirect modulation mode and a transmitter having transmitting circuit 301-4 in the direct modulation mode. Transmitting circuit 301-3 and 301-4 are connected with antenna 302-3 via switch 313. Transmitting circuit 301-1~3 are supplied with transmission signals via MIMO processing circuit 304, and transmitting circuit 301-4 is directly supplied with a transmission signal not via MIMO processing circuit 304.

【0077】

Power supply control circuit 303 controls the supply of power to be supplied to transmitting circuits 301-1 through 301-3 based on a power supply control signal. MIMO processing circuit 304 has at least one of or all

of a modulating function, a coding function and a weighting/mapping function. MIMO processing circuit 304 includes modulator 305 and is capable of changing a symbol rate and the number of multilevel of modulation according to a modulation control signal. MIMO processing circuit 304 outputs the transmission signal generated based on the input signal and the modulation control signal to transmitting circuits 301-1 through 301-3.

【0078】

Receiving device 306 comprises a plurality of receivers, power supply control circuit 309, MIMO processing circuit 310, level detector 311 and error rate measuring unit 312. The plurality of receivers comprises a receiver having receiving circuit 307-1 in the indirect demodulation mode connected to antenna 208-1, a receiver having receiving circuit 307-2 in the indirect demodulation mode connected to antenna 308-2, and a receiver having receiving circuit 307-3 in the indirect demodulation mode connected with antenna 308-3 and a receiver having receiving circuit 307-4 in the direct demodulation mode. Receiving circuit 307-3 and 307-4 are connected with antenna 308-3 via switch 314. Power supply control circuit 309 controls power to be supplied to receiving circuits 307-1 through 307-3 based on a power supply control signal. MIMO processing circuit 310 has at least one of or all of a modulating function, a decoding function and a weighting/mapping function. MIMO processing circuit 310 generates reception data based on the reception signals input from receiving circuits 307-1 through 307-3 and outputs the reception data. MIMO processing circuit 310 estimates a channel matrix based on the reception signals input from receiving circuits 307-1 through 307-3, and outputs the estimated channel matrix. Level

detector 311 detects a reception level based on reception level signals input from receiving circuits 307-1 through 307-4, and outputs the detected reception level. Error rate measuring unit 312 measures a bit error rate or a frame error rate based on the reception data output from MIMO processing circuit 310 and receiving circuit 307-4, and outputs the error rate.

【0079】

Transmitting circuit 304-4 and receiving circuit 307-4 employ any one of ASK, FSK, BPSK, QPSK and DQPSSK as a modulation/demodulation process. Transmitting circuit 304-4 modulates input data into a transmission carrier, and receiving circuit 307-4 demodulates data directly from a reception signal. Such modulation/demodulation is referred to as direct modulation/demodulation. A symbol rate used in transmitting circuit 304-4 and receiving circuit 307-4 is set to a value higher than the symbol rate used in transmitting circuits 301-1 through 301-3 and in receiving circuits 307-1 through 307-3 in the indirect modulation/demodulation mode.

【0080】

The radio communication device according to the present variant differs from the radio communication device shown in Fig. 2 in that antennas are shared. Transmitting circuit 301-3 and transmitting circuit 301-4 are connected with antenna 302-3 through switch 313. Receiving circuit 307-3 and receiving circuit 307-4 are connected to antenna 308-3 through switch 314. Antenna 302-3 and antenna 308-3 are shared. Switches 313, 314 that are operated by the power supply control signals are provided respectively in transmitter 300 and in receiver 306.

【0081】

The present variant offers the same advantages as those described in the second embodiment, but additionally makes the apparatus smaller in size because the antennas are shared. Though the switches are used in the illustrated variant, general antenna sharing units may be employed instead.

【0082】

A third embodiment of the present invention will be explained with reference to Fig.4. Fig. 4 is a block diagram of a radio communication device according to the third embodiment of the present invention. The radio communication device has transmitter 400 and receiver 406. Since communications are normally bidirectional, a plurality of radio communication device are positioned in facing relation to each other for communications therebetween. In this embodiment, transmitter 400 and receiver 406 are a transmitter and a receiver, respectively, of radio communications devices that face each other. Further, although not shown, the radio communication device has a control section for controlling the operation of the radio communication device by estimating multipath interference, and judging whether or not the error rate is good.

【0083】

Transmitting device 400 comprises a plurality of transmitters, power supply control circuit 403, MIMO processing circuit 404 and selector 415. Each of transmitting circuits is capable of selecting a direct modulation mode or an indirect modulation mode as a modulation process. The plurality of transmitters include a transmitter having transmitting circuit 401-1 connected with antenna 402-1, a transmitter having transmitting circuit 401-2 connected with antenna 402-2 and a transmitter having transmitting circuit 401-3 connected with antenna 402-3. Transmitting circuits 401-1 through 401-3

are supplied with transmission signals through MIMO processing circuit 404 and are supplied with data signals through selector 415. Selector 415 makes a setting for selecting transmission signals or data signals to be used by transmitting circuits 401-1 through 401-3. Transmitting circuits 401-1 through 401-3 have respective modulators for modulating a carrier with the data signals that are input through selector 415.

【0084】

Power supply control circuit 403 controls the supply of power to be supplied to transmitting circuits 401-1 through 401-3 based on a power supply control signal. MIMO processing circuit 404 has at least one of or all of a modulating function, a coding function and a weighting/mapping function. MIMO processing circuit 404 includes modulator 405 and is capable of changing a symbol rate and the number of multilevel of modulation according to a modulation control signal. MIMO processing circuit 404 outputs the transmission signal generated based on the input signal and the modulation control signal to transmitting circuits 401-1 through 401-3. Selector 415 has functions to distribute data to transmitting circuits 401-1 through 401-3 and to select the direct modulation mode or the indirect modulation mode as the modulation process.

【0085】

Receiving device 406 comprises a plurality of receivers, power supply control circuit 409, MIMO processing circuit 410, level detector 411, error rate measuring unit 412, and selector 416. Each of transmitting circuits is capable of selecting a direct demodulation mode or an indirect demodulation mode as a modulation process. The plurality of receivers comprises a receiver having receiving circuit 407-1 connected with antenna 408-1, a

receiver having receiving circuit 407-2 connected with antenna 408-2, and a receiver having receiving circuit 407-3 connected with antenna 408-3. Power supply control circuit 409 controls power to be supplied to receiving circuits 407-1 through 407-3 based on a power supply control signal. MIMO processing circuit 410 has at least one of or all of a modulating function, a decoding function and a weighting/mapping function. MIMO processing circuit 410 generates reception data based on the reception signals input from receiving circuits 407-1 through 407-3 and outputs the reception data. MIMO processing circuit 410 estimates a channel matrix based on the reception signals input from receiving circuits 407-1 through 407-3, and outputs the estimated channel matrix. Level detector 411 detects a reception level based on reception level signals input from receiving circuits 407-1 through 407-3, and outputs the detected reception level. Error rate measuring unit 412 measures a bit error rate or a frame error rate based on the reception data output from MIMO processing circuit 410 and selector 416, and outputs the error rate. Selector 416 has functions to distribute data output from receiving circuits 407-1 through 407-3 and to select the direct demodulation mode or the indirect demodulation mode as the demodulation process.

【0086】

Any one of ASK, FSK, BPSK, QPSK and DQPSSK is employed as the direct modulation/demodulation mode. Transmitting device 400 modulates input data into a transmission carrier, and receiving device 406 demodulates data directly from a reception signal. A symbol rate is set to a value higher than the symbol rate used in the transmitting circuits and the receiving circuits in the indirect modulation mode. The indirect

modulation/demodulation mode may employ any one of multilevel PSK or multilevel QAM and OFDM using multilevel PSK or multilevel QAM for primary modulation.

【0087】

The present radio communications device performs a procedure for making settings on the transmitting and receiving circuits as shown in Fig. 12. First, selector 415 is set to the direct modulation mode, and selector 416 is set to the direct demodulation mode (step S81). In this state, communications are performed in the direct modulation/demodulation mode. Power control circuit 403 controls the supply of power to supply electric power to transmitting circuit 401-1, and power control circuit 409 controls the supply of power to supply electric power to receiving circuit 407-1(step S82). Therefore, transmitting circuit 401-1 and receiving circuit 407-1 are brought into a state capable of communicating with each other.

【0088】

Error rate measuring unit 412 measures an error rate (step S83). The control section records the combination of transmitters and receivers and the error rate. When the measurement of the error rate is finished, power supply control circuits 403, 409 control the power supplies to stop the supply of electric power to transmitting circuit 401-1 and receiving circuit 407-1.

【0089】

It is determined whether or not the measurement of error rates for all combinations of transmitting and receiving circuits is completed. If there is a combination of transmitting and receiving circuits for which an error rate has not yet been measured (step S84-NO), then the combination of the transmitting and receiving circuits is changed, and transmitting and receiving

circuits in another combination are energized into operation. Control then goes back to step S83 to measure an error rate. If the measurement of error rates for all combinations of the transmitting and receiving circuits is completed (step S84-YES), then a combination of a transmitting circuit and a receiving circuit with the best error rate is searched from the recorded error rates corresponding to the combinations of the transmitter and receiver. If the best error rate is determined as an error rate sufficiently appropriate for communications (low error rate) (step S86-YES), then subsequent communications are performed using that combination of transmitting and receiving circuits (step S87). If the best error rate is not an error rate sufficiently appropriate for communications (step S86-NO), then the control section determines that the effect of multipath interference is strong, and sets selector 415 to the indirect modulation mode and selector 416 to the indirect demodulation mode (step S88). Thereafter, a setting process in the indirect modulation/demodulation mode is performed in which radio communications according to the normal MIMO process are set, or a symbol rate and the number of multilevel of modulation are determined according to any one of the processes described above in the first embodiment and in the variants thereof (step S89).

【0090】

In Fig. 12, error rates are measured for all combinations of transmitting and receiving circuits. However, error rates may not be measured for all combinations of transmitting and receiving circuits. When it is determined that a sufficiently appropriate error rate is measured, then subsequent error rate measurements may be skipped, and communications may be performed with the combination of transmitting and receiving circuits

for which the error rate has been measured. Electric power consumption may be reduced if the power supplies of transmitting and receiving circuits which are not used are turned off.

【0091】

The present embodiment offers the same advantages as those described in the second embodiment and in the variant thereof. Though the transmitting and receiving circuits according to the present embodiment are slightly more complex, the number of antennas is smaller than in the second embodiment, and no switches are required, unlike in the variant of the second embodiment. Another advantage is that only one transmission amplifier of a transmitting circuit is connected to each antenna, and only one reception amplifier of a receiving circuit is connected to each antenna

【0092】

As explained hereinabove, by detecting the state of signal propagation, such as an effect of multipath interference, and changing a symbol rate in MIMO system, it is possible to provide a radio communications device and a radio communications system which are capable of transmitting data at a high-rate while suppressing electric power consumption.

【0093】

In the block diagrams shown in the above embodiments, radio communication devices having a transmitter and a receiver, respectively, face each other, for illustrative purposes. However, a radio communication device usually has both a transmitter and a receiver. In this case, the antennas of the transmitter and the receiver can be shared by a sharing unit or a switch. The transmission signal/reception signal processing circuits

have a function to perform serial-to-parallel conversion (or vice versa) of data. This function may be provided outside of the transmission signal/reception signal processing circuits. If the data are parallel, then the parallel data itself may be handled. Though the error rate measuring unit has been described in each of the above embodiments, the error rate measuring unit may not be hardware-implemented, but may be software-implemented for detecting an error rate, a retransmission rate, or an index correlated to an error rate. The plural propagation detectors which have been described above, i.e., the level detector, the error rate measuring unit, and the function of outputting a channel matrix, are provided when necessary, and not all of them need to be provided. Although not specifically described, an increase in the transmission capacity due to spatial multiplexing according to normal MIMO technology, a spatial diversity effect due to time-space coding, and optimum electric power distribution between transmitters using information of independent spatial transmission paths are also applicable to the embodiments of the present invention. In all of the embodiments, three or four transmitters and three or four receivers have been described for illustrative purposes. However, insofar as a plurality of transmitters and a plurality of receivers are provided, the numbers of transmitters and receivers are not limited to any particular values.

【0094】

Depending on the intensity of a multipath interference, the symbol rate is controlled to achieve high-rate transmission with optimized electric power consumption. Radio communications devices using frequencies of 10 GHz or higher, particularly frequencies of millimeter waves (30 to 300 GHz), even with an array of antennas, may be reduced in size. If multipath interference

is weak, the radio communications device is operated in the direct modulation/demodulation mode, thereby achieving high-rate communications with low electric power consumption. If multipath interference is strong, then though the electric power consumption increases, the possibility of communication interruptions due to multipath interference is lowered, and hence communications can be continued while maintaining a certain transmission rate.

【Brief Description of the Drawings】

【0095】

【Fig.1】 Fig. 1 is a block diagram of a radio communication device according to a first embodiment of the present invention.

【Fig. 2】 Fig. 2 is a block diagram of a radio communication device according to a second embodiment of the present invention.

【Fig. 3】 Fig. 3 is a block diagram of a radio communication device according to a variant of the second embodiment of the present invention.

【Fig. 4】 Fig. 4 is a block diagram of a radio communication device according to a third embodiment of the present invention.

【Fig. 5】 Fig. 5 is a flowchart of a process of determining a symbol rate according to a first embodiment.

【Fig. 6】 Fig. 6 is a flowchart of a process of determining a symbol rate according to a first variant.

【Fig. 7】 Fig. 7 is a flowchart of a process of determining a symbol rate and the number of multilevel of modulation according to a second variant.

【Fig. 8】 Fig. 8 is a flowchart of a process of determining a symbol rate and the number of multilevel of modulation according to a third variant;

【Fig. 9】 Fig. 9 is a flowchart of a process of determining a symbol rate according to a fourth variant.

【Fig. 10】 Fig. 10 is a flowchart of a process of determining a symbol rate and the number of multilevel of modulation according to a fifth variant.

【Fig. 11】 Fig. 11 is a flowchart of a process of setting a transmitter and a receiver according to the second embodiment.

【Fig. 12】 Fig. 12 is a flowchart of a process of setting a transmitter and a receiver according to the third embodiment.

【Fig. 13】 Fig. 13 is a graph showing by way of example the relationship between reception electric power levels and error rates which determines the intensity of multipath interference.

【Fig. 14】 Fig. 13 is a graph showing the relationship between the number of independent spatial transmission paths and multipath levels according to MIMO.

【Fig. 15】 Fig. 15 is a block diagram of a conventional radio communication device.

【Explanation of Symbols】

100, 200, 300, 400 transmitting device

101-1~3, 201-1~4, 301-1~4, 401-1~3 transmitting circuit

102-1~3, 202-1~4, 302-1~3, 402-1~3 antenna

103, 203, 303, 403 power control circuit

104, 204, 304, 404 MIMO processing circuit

105, 205, 305, 405 modulator

106, 206, 306, 406 receiving device

107-1~3, 207-1~4, 307-1~4, 407-1~3 receiving circuit

108-1~3, 208-1~4, 308-1~3, 408-1~3 antenna

109, 209, 309, 409 power control circuit

110, 210, 310, 410 MIMO processing circuit

111, 211, 311, 411 level detector

112, 212, 312, 412 error rate measuring unit

313, 314 switch

415, 416 selector

1500 transmitting device

1501-1~3 transmitting circuit

1502-1~3 antenna

1504 MIMO processing circuit

1506 receiving device

1507-1~3 receiving circuit

1508-1~3 antenna

1510 MIMO processing circuit

Fig. 1

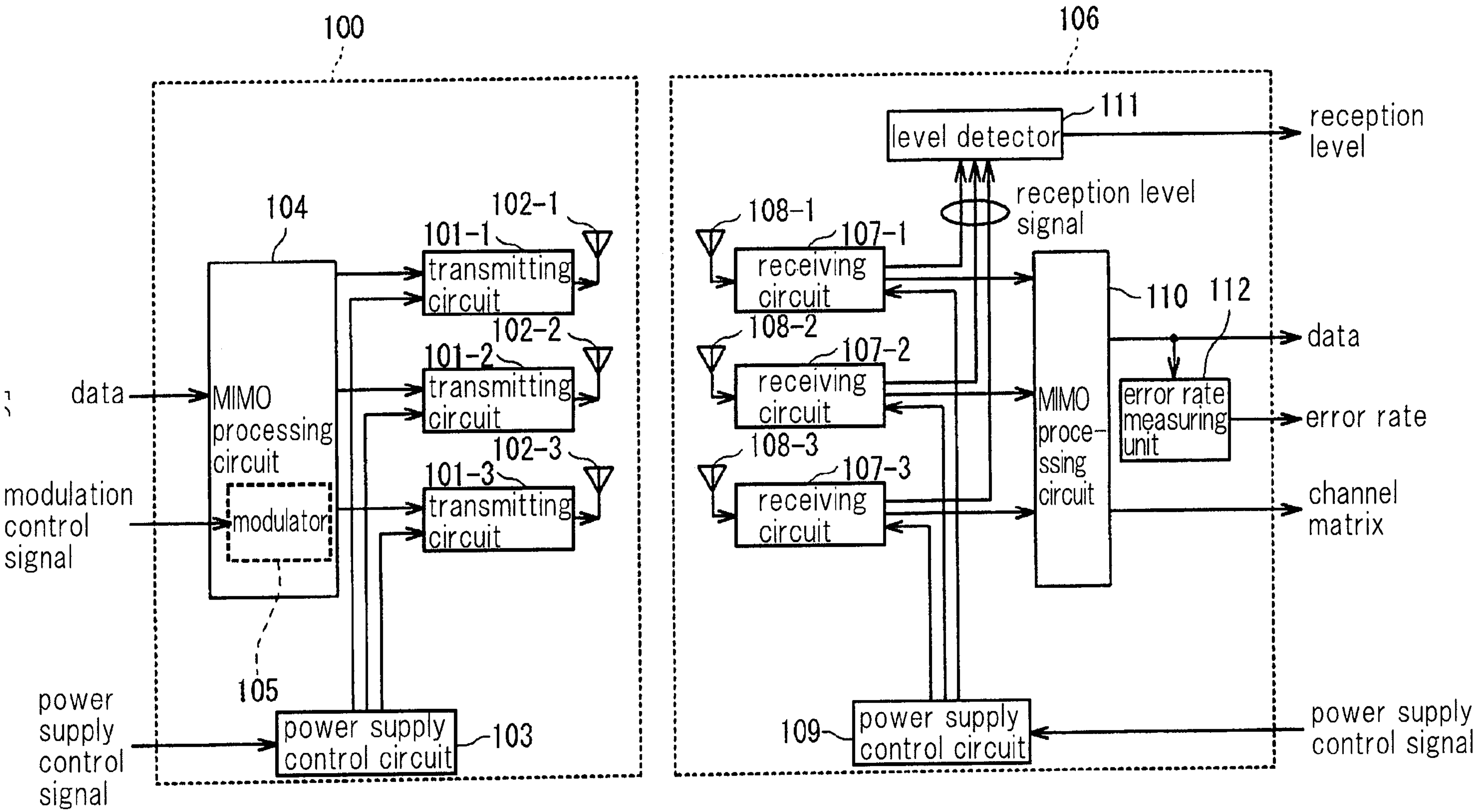

100
106
104
102-1
101-1
transmitting circuit
102-2
101-2
transmitting circuit
102-3
101-3
transmitting circuit
data
MIMO processing circuit
modulation control signal
modulator
105
power supply control signal
power supply control circuit
103
level detector
111
reception level
reception level signal
108-1
107-1
receiving circuit
108-2
107-2
receiving circuit
108-3
107-3
receiving circuit
MIMO proce-ssing circuit
110
112
data
error rate measuring unit
error rate
channel matrix
109
power supply control circuit
power supply control signal

Fig.2

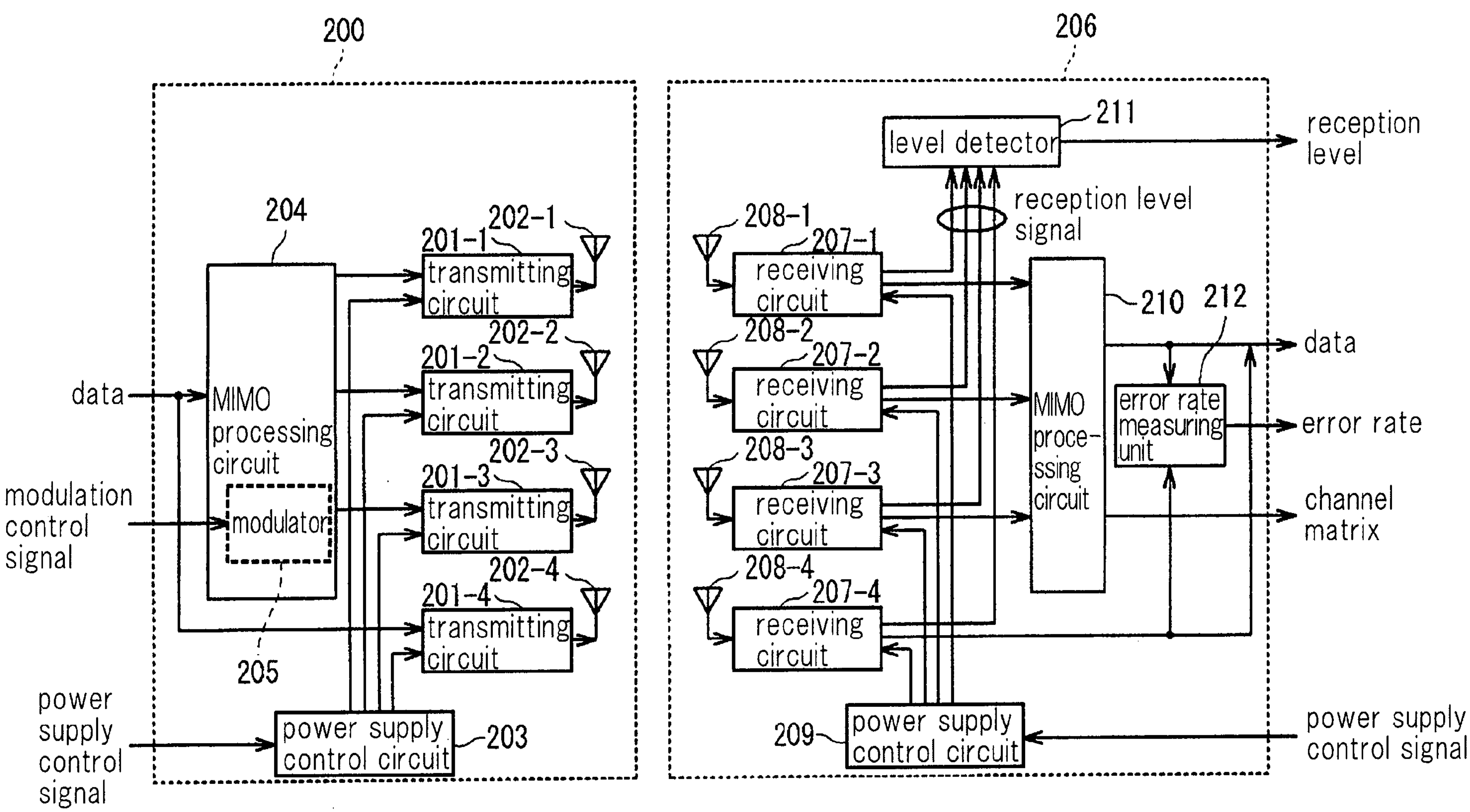
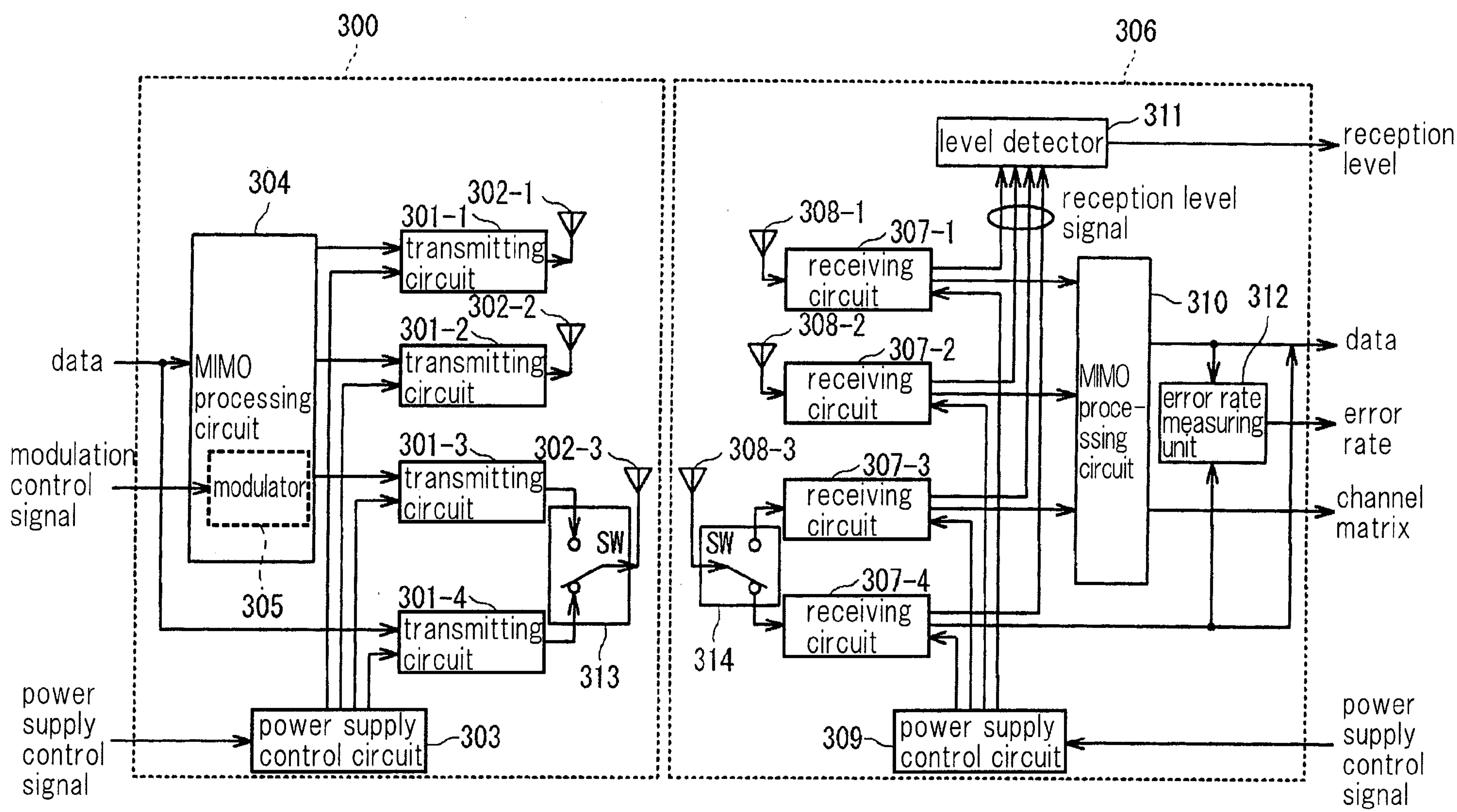

200
204
MIMO processing circuit
modulator
205
201-1
202-1
transmitting circuit
201-2
202-2
transmitting circuit
201-3
202-3
transmitting circuit
201-4
202-4
transmitting circuit
power supply control circuit
203
data
modulation control signal
power supply control signal
206
level detector
211
reception level
reception level signal
208-1
207-1
receiving circuit
208-2
207-2
receiving circuit
208-3
207-3
receiving circuit
208-4
207-4
receiving circuit
MIMO proce-ssing circuit
210
212
error rate measuring unit
data
error rate
channel matrix
209
power supply control circuit
power supply control signal

Fig.3



300
306
data
modulation control signal
power supply control signal
304
MIMO processing circuit
modulator
305
301-1
transmitting circuit
302-1
301-2
transmitting circuit
302-2
301-3
transmitting circuit
302-3
SW
313
301-4
transmitting circuit
power supply control circuit
303
level detector
311
reception level
reception level signal
308-1
307-1
receiving circuit
308-2
307-2
receiving circuit
308-3
SW
314
307-3
receiving circuit
307-4
receiving circuit
MIMO proce-ssing circuit
310
312
error rate measuring unit
data
error rate
channel matrix
309
power supply control circuit
power supply control signal

Fig.4

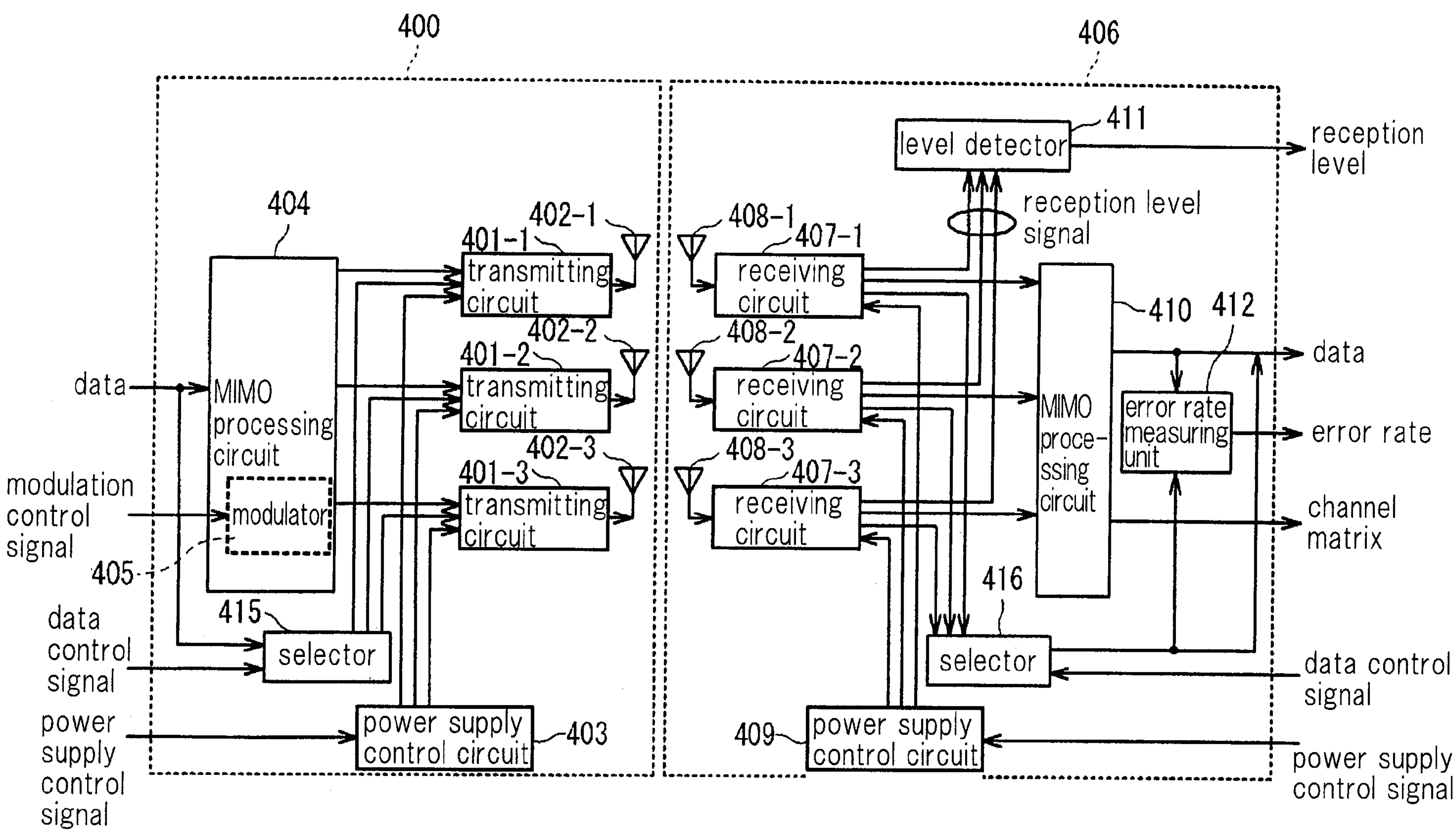

400
406
404
MIMO processing circuit
modulator
405
data
modulation control signal
data control signal
power supply control signal
415
selector
power supply control circuit
403
401-1
402-1
transmitting circuit
401-2
402-2
transmitting circuit
401-3
402-3
transmitting circuit
408-1
407-1
receiving circuit
408-2
407-2
receiving circuit
408-3
407-3
receiving circuit
level detector
411
reception level
reception level signal
MIMO proce-ssing circuit
410
412
error rate measuring unit
data
error rate
channel matrix
416
selector
data control signal
409
power supply control circuit
power supply control signal

Fig.5

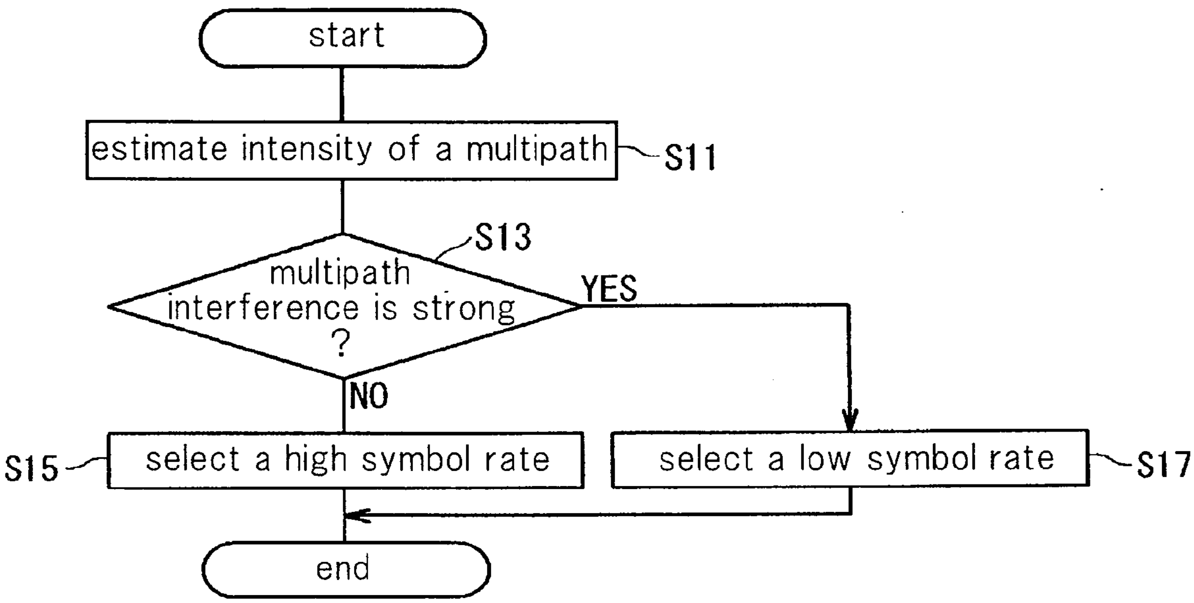

start
estimate intensity of a multipath
S11
S13
multipath interference is strong ?
YES
NO
S15
select a high symbol rate
select a low symbol rate
S17
end

Fig.6

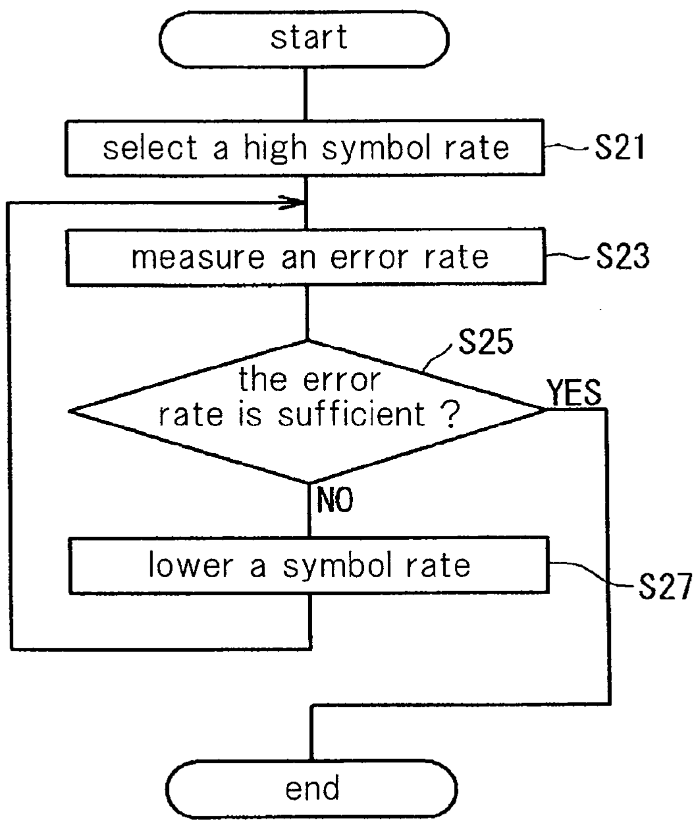
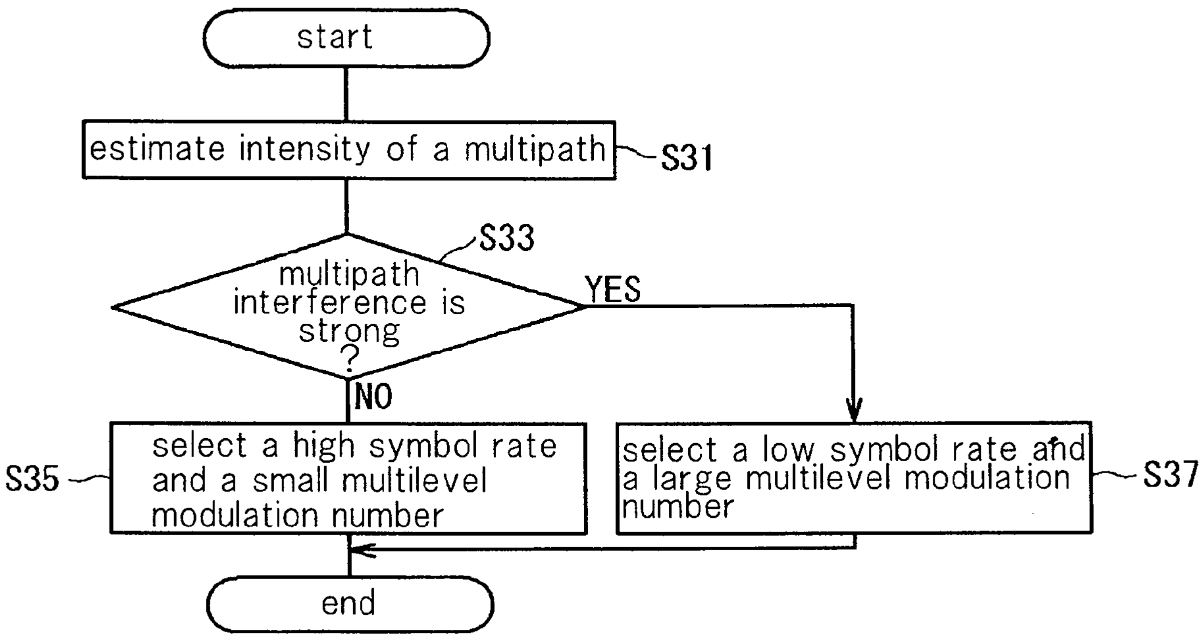
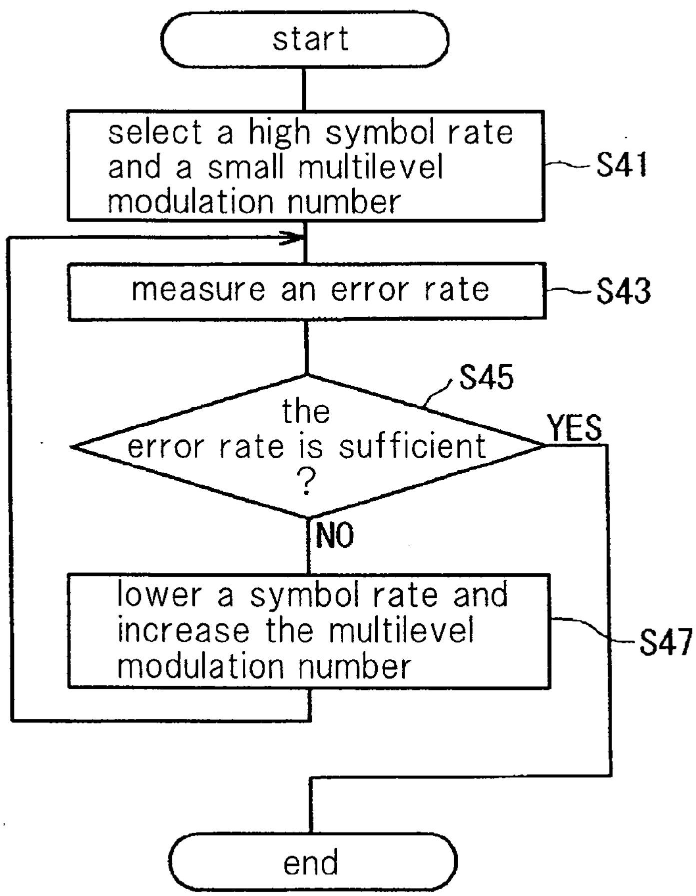

start
select a high symbol rate
S21
measure an error rate
S23
S25
the error rate is sufficient ?
YES
NO
lower a symbol rate
S27
end

Fig.7



start
estimate intensity of a multipath
S31
S33
multipath interference is strong ?
YES
NO
select a high symbol rate and a small multilevel modulation number
S35
select a low symbol rate and a large multilevel modulation number
S37
end

Fig.8



start
select a high symbol rate and a small multilevel modulation number
S41
measure an error rate
S43
S45
the error rate is sufficient ?
YES
NO
lower a symbol rate and increase the multilevel modulation number
S47
end

Fig.9

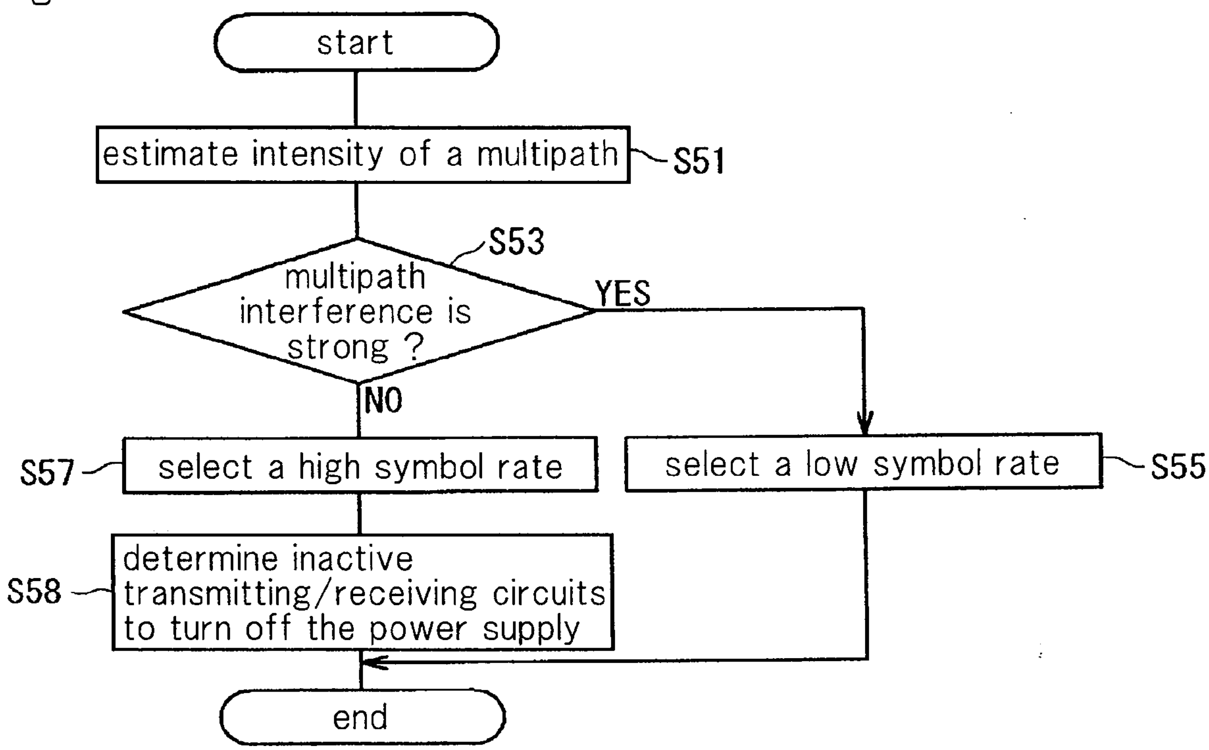

start
estimate intensity of a multipath
S51
S53
multipath interference is strong ?
YES
NO
select a high symbol rate
S57
select a low symbol rate
S55
determine inactive transmitting/receiving circuits to turn off the power supply
S58
end

Fig.10

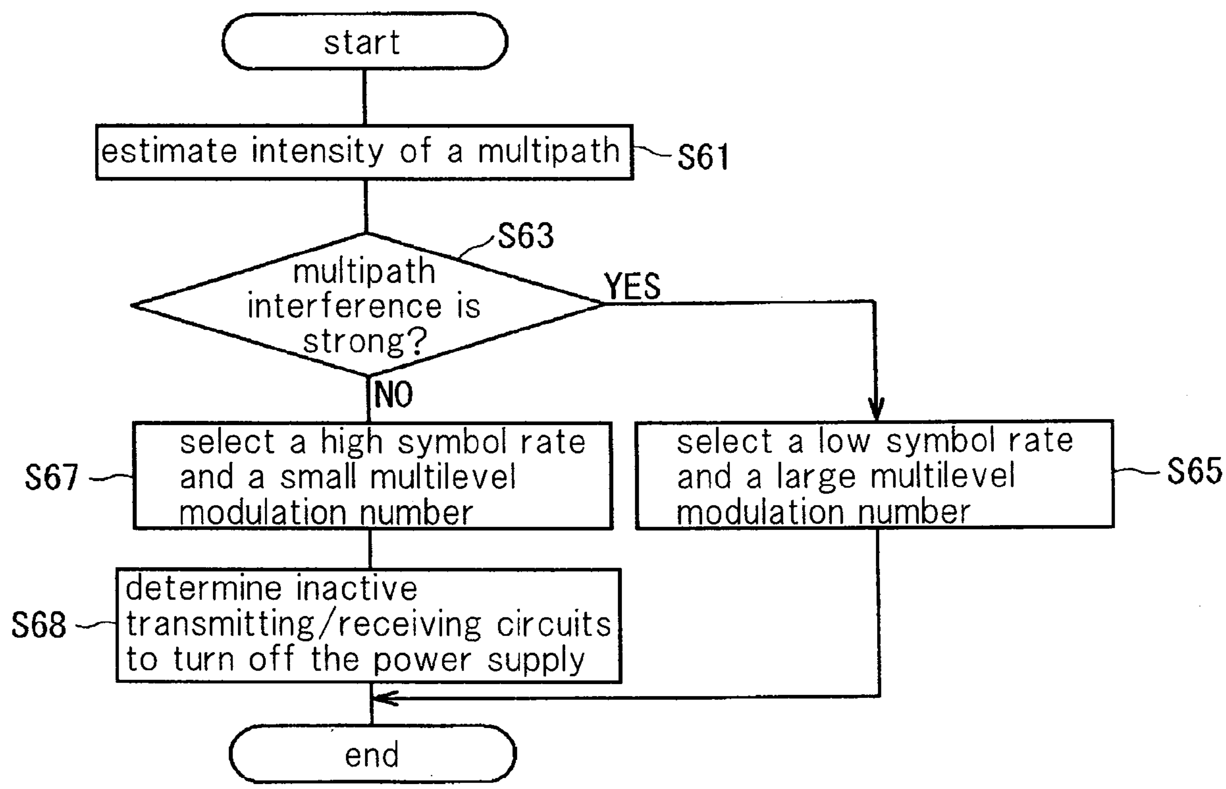

start
estimate intensity of a multipath
S61
S63
multipath interference is strong?
YES
NO
select a high symbol rate and a small multilevel modulation number
S67
select a low symbol rate and a large multilevel modulation number
S65
determine inactive transmitting/receiving circuits to turn off the power supply
S68
end

Fig.1 1

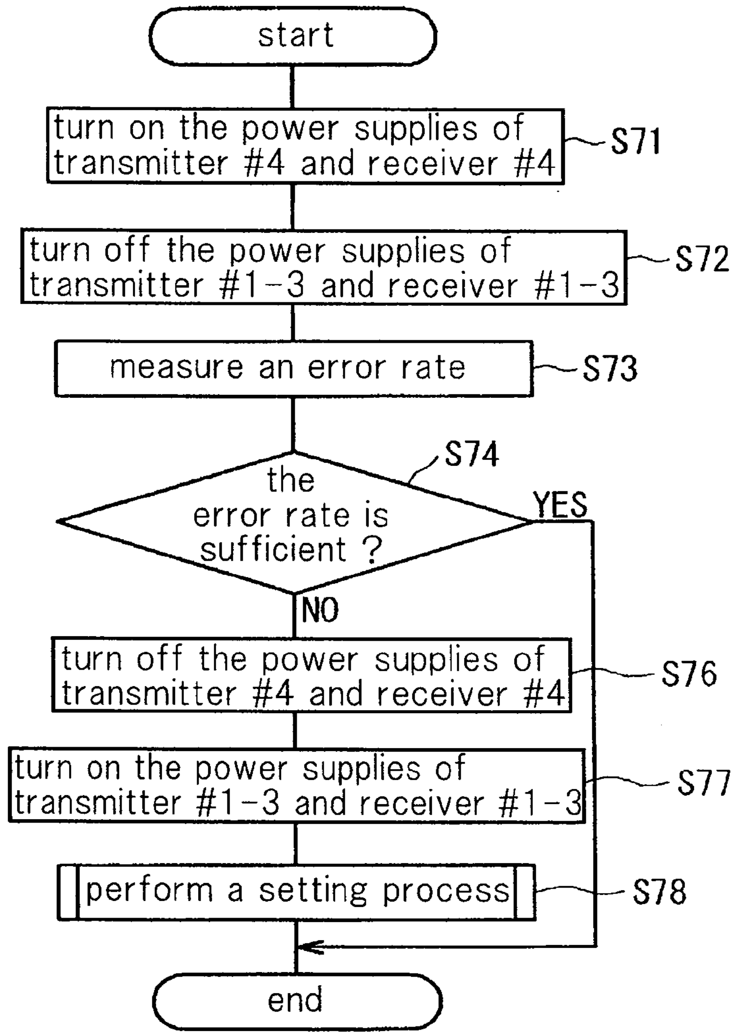

start
turn on the power supplies of transmitter #4 and receiver #4
S71
turn off the power supplies of transmitter #1-3 and receiver #1-3
S72
measure an error rate
S73
the error rate is sufficient ?
S74
YES
NO
turn off the power supplies of transmitter #4 and receiver #4
S76
turn on the power supplies of transmitter #1-3 and receiver #1-3
S77
perform a setting process
S78
end

Fig.12

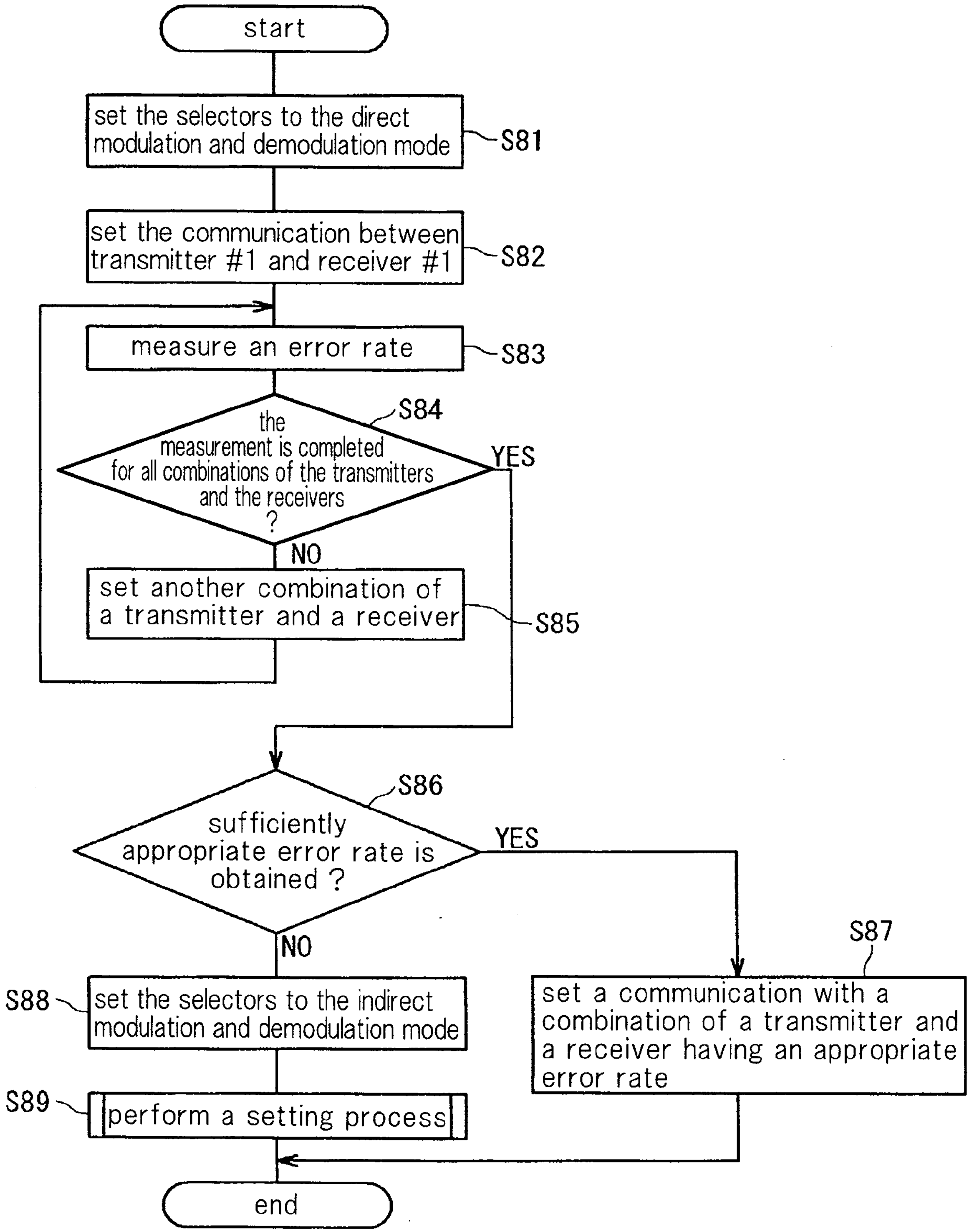

start
set the selectors to the direct modulation and demodulation mode
S81
set the communication between transmitter #1 and receiver #1
S82
measure an error rate
S83
S84
the measurement is completed for all combinations of the transmitters and the receivers ?
YES
NO
set another combination of a transmitter and a receiver
S85
S86
sufficiently appropriate error rate is obtained ?
YES
NO
S87
set a communication with a combination of a transmitter and a receiver having an appropriate error rate
S88
set the selectors to the indirect modulation and demodulation mode
S89
perform a setting process
end

Fig.13

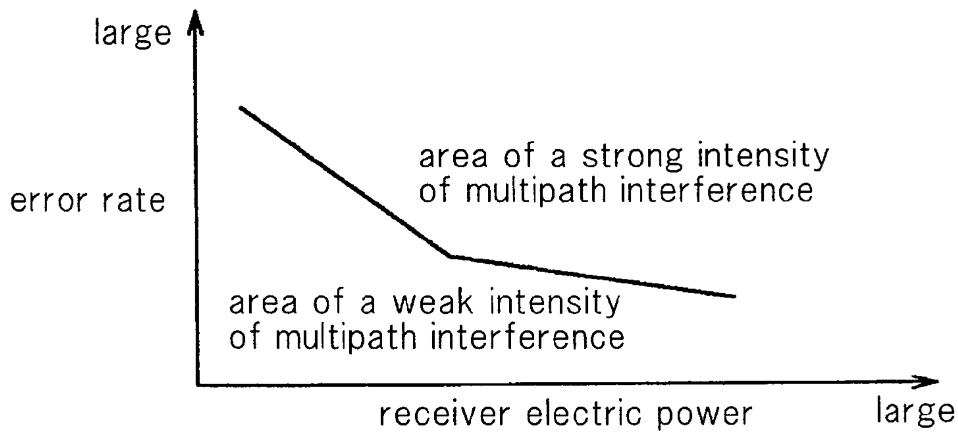

large
error rate
area of a strong intensity
of multipath interference
area of a weak intensity
of multipath interference
receiver electric power
large

Fig.14

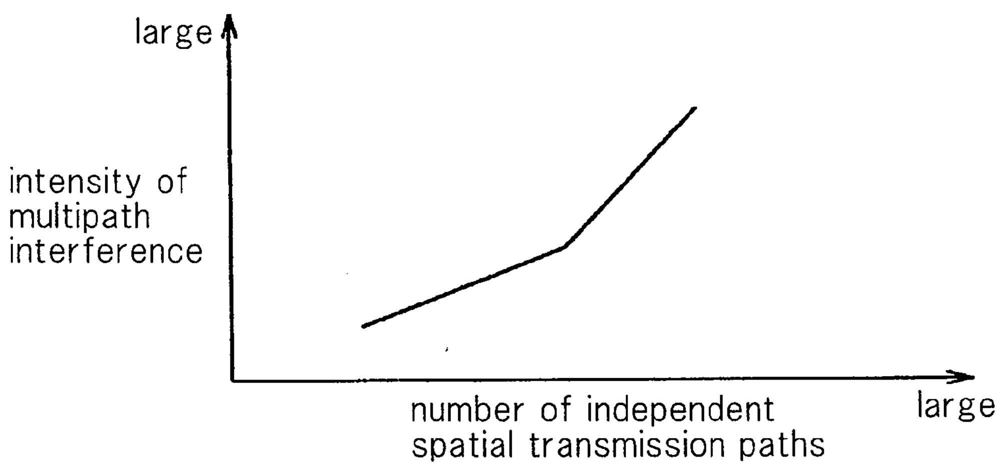
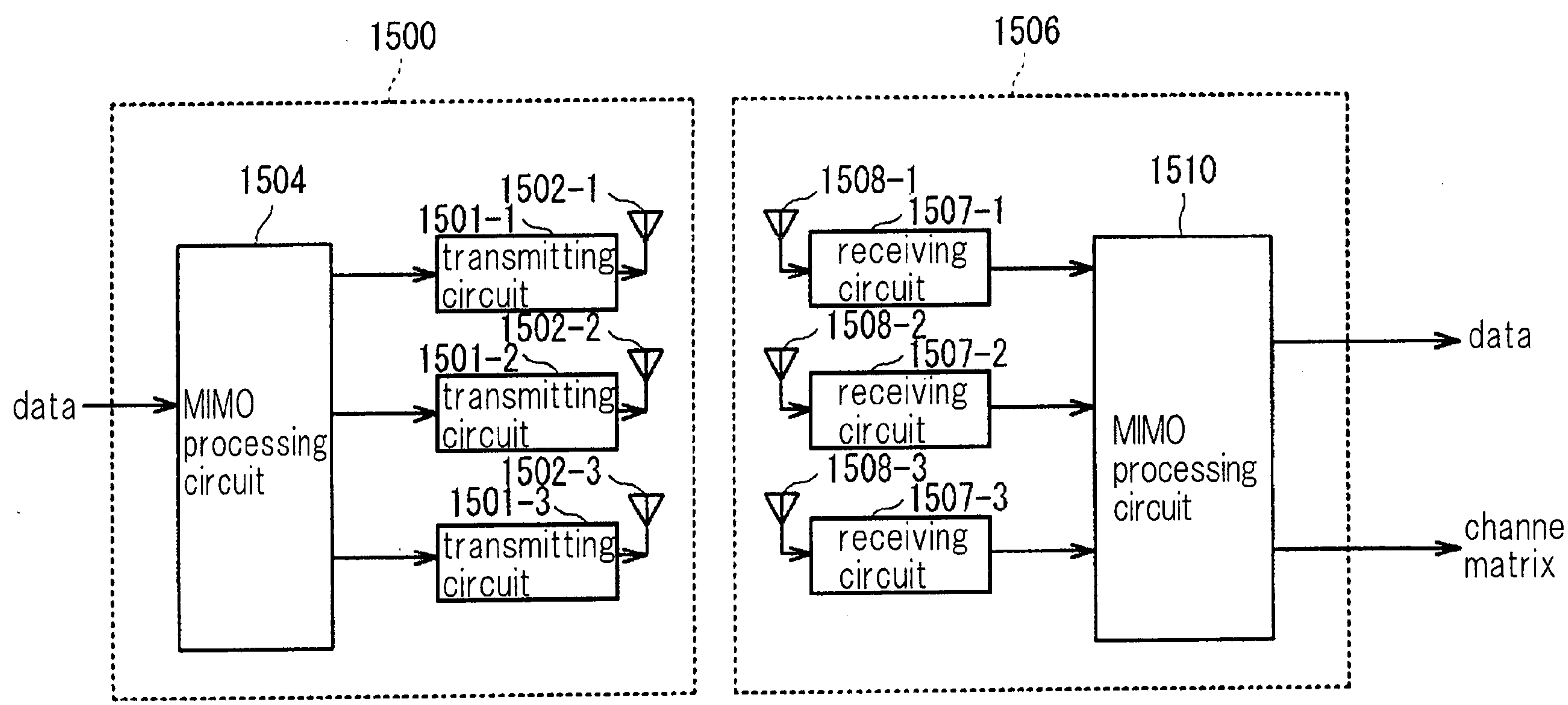

large
intensity of
multipath
interference
number of independent
spatial transmission paths
large

Fig.15


1500
1504
data
MIMO processing circuit
1502-1
1501-1
transmitting circuit
1502-2
1501-2
transmitting circuit
1502-3
1501-3
transmitting circuit
1506
1508-1
1507-1
receiving circuit
1508-2
1507-2
receiving circuit
1508-3
1507-3
receiving circuit
1510
MIMO processing circuit
data
channel matrix

【Document Name】 Abstract

【Abstract】

【Object】 An object of the present invention is to provide a radio communications device and a radio communications system which are capable of transmitting data at a high-rate while suppressing electric power consumption.

【Solution】 A radio communications device includes a transmitting device, a receiving device, a propagation detecting section, and a symbol rate setting section. The transmitting device comprises a transmitter having a plurality of antennas and a plurality of transmitting circuits, and a transmission signal processing section. The transmission signal processing section outputs to the transmitter a transmission signal that is generated based on an input transmission data. The transmission signal processing section has a modulator that generates transmission signals. The receiving device comprises a receiver having a plurality of antennas and a plurality of receiving circuits, and a reception signal processing section. The reception signal processing section generates reception data based on the reception signal output from the receiver. The reception signal processing section has a demodulator that demodulates reception signals having a plurality of symbols. The propagation detecting section detects propagation state of radio waves. The symbol rate setting section selects a symbol to be communicated from a plurality of symbol rates based on the detected propagating state and sets the selected symbol rate to the modulator and to the demodulator.

【Representative Drawing】 Fig. 1